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BIOCYBERNETIC CONTROL IN MAN-MACHINE INTERACTION: FINAL TECHNICAL REPORT 1974-75

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Principal Investigator: J.J. VIDAL

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COMPUTER SCIENCE DEPARTMENT

School of Engineering and Applied Science
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Los Angeles

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This research is a continuation of a program aimed at incorporating EEG "evoked responses" in man-machine communication. A methodology for the single-epoch discrimination of evoked responses has been developed. The approach is compatible with real-time computing. High rates of stimulus identification have been obtained with several types of visual stimuli.

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(July 1, 1974 to June 30, 1975)

Jacques J. Vidal, Principal Investigator

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BIOCYBERNETIC CONTROL IN MAN-MACHINE INTERACTION

FINAL TECHNICAL REPORT 1974-1975

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CONTENTS

1. ORIENTATION

The present document is the final annual report for the BIOCYBERNETIC CONTROL IN MAN-MACHINE INTERACTION project at UCLA conducted under Advanced Research Projects Agency Contract No. N00014-69-A-0200-4055. The project began in April 1973 under a different contract. The long term goals were described in detail in earlier proposals (UCLA Eng-P2465-N-73, P-2719-C-4 and UCLA-Eng-7535) and are reviewed briefly below.

The ultimate goal of the project is to devise methods to incorporate electrophysiological brain signals into man-machine communication procedures. The implementation and evaluation of such procedures deals with perceptual, cognitive and affective modes of communication.

In conventional man-machine dialogues using computer terminals, the terminal provides most of the external environment and generates stimulus inputs to the operator in the form of graphic or alphanumeric displays. Typically the response is the selection of a sequence of keyboard commands. This motor behavior is chosen based on an analysis of the situation. A closer coupling could be attained if the terminal could access the covert as well as the overt responses, and bypass to some degree the requirement for an explicit motor output.

A closely coupled man-machine interface would require the use of a communication mode with the following characteristics:

1. Adequate bandwidth; i.e. quick access.
2. Low overhead in terms of voluntary motor activity.
3. Stability and repeatability.

event related brain potentials seem to be the most suitable biosignals for development of the intended application.

The experimental approach consists of identifying features in the EEG (evoked responses) which constitute feasible codes for use in directly communicating specific messages relevant to interactive man-machine communication. Such messages would be, for example, the recognition of a photograph (matching), its acceptance or rejection based on some criterion, the choice between visual alternatives (a visual light pen), or the appraisal of a given environmental event in terms of its meaningfulness or significance to the subject/operator.

2. Progress to Date.

The UCLA BIOCYBERNETIC CONTROL IN MAN-MACHINE INTERACTION Project has been underway at the Brain Computer Interface Laboratory (BCI) since July 1973 under ARPA sponsorship. Accomplishments to date for the ensemble of the project fall into three categories, namely:

1. Evoked response experiment results (2.1).
2. Computer support system design and development (2.2).
3. Development of computer methodology and application software for real-time online identification of event related EEG signals.(2.3)

The accomplishments during the first year and a half have been described in the Final Technical Report 1973-74, and in the Semi-Annual Technical Report 1974-75. The present document covers the second half of the second year (1974-75). The salient items are summarized in the present section.

2.1 EVOKED RESPONSE EXPERIMENT RESULTS

2.1.1 Color Experiments

The data collected in the previous period has been extensively analyzed, using both the BCI version of Stepwise Discriminant Analysis, and the new BMD version, P7M. In the current analyses, all the data samples had an opportunity to be selected for inclusion into the decision rule. Also, a procedure suggested by Tatsuoka (1971) for computing the contributions of each variable

in the decision rule to the classification of each group has been utilized. From this procedure, the EEG COLOR CODE for each subject can be displayed. These results are tabulated in the following section.

The adoption of a first half/second half training/testing division of the data has resulted from a desire to approximate more closely the procedure that is expected to be used online, where data is collected for the generation of a training set, and then the resulting classification function is applied to subsequent data.

2.1.2 Pattern-Position Experiments

An additional series of experiments testing the effect of retinal position variation was conducted using various display configurations in a search for a more optimal stimulus for the visual light pen experiments to be performed. These experiments were analyzed offline, in batch mode, and the results were used to select the display parameters which gave the best results, in terms of % correctly classified stimuli and Mutual Information transfer. These results are described in detail in the following section.

2.1.3 Online Experiments

In June of 1975 the first online, real time evoked response classification experiments were successfully completed. The visual light pen experiment was implemented on a three computer network

in the BCI Lab. Some of the details of this accomplishment are described in the following section.

2.2 Computer System Developments

In order to implement the online classification experiments, towards which the BCI lab had directed its efforts from inception, numerous hardware changes were designed and constructed. In particular, three computers were networked together so that they could talk fluently to each other, each performing its particular function. The SDS 930 acts as real time experiment controller, data collecter, data analyzer, and generates archive tapes and printed and punched output. The IMLAC PDS-1 is an intelligent graphics display computer, and handles the CRT display and refresh chores, while the SDS 920 acts as an Input/Output buffer, and Imlac program storage computer.

2.3 Computer Methodology and Software Development

A massive effort was undertaken to bring the capabilities of online, real time EEG evoked response data analysis and classification to the operational stage by the close of the contract year.

The major problems solved involved the generation of a virtual link loader operating system. This linking scheme allows a data collection program (the Scheduler,Link 20) to collect data, then replace itself in core with the data analysis programs(BCI SDA), and calculate the linear discriminant rules. Once the rules are

obtained, the SDA link (link 40) replaces itself with the Scheduler again for the performance of the online data classification.

3. EVOKED RESPONSES RESULTS SUMMARIES

3.1 COLOR EXPERIMENTS

3.1.1 Methods

The methods used for the collection of the color evoked response data were detailed in the Semi-Annual Technical Report 1974-75, and will be reviewed again below.

Fifteen subjects were evaluated, ten were used, all were aged 19-24. Each was given a Ishihara test of color discrimination. Individual recording sessions were conducted and required two hours.

Standard silver disc electrodes are applied with electroconductive paste at five locations on the scalp: Fpz, Pz, Oz, O1 and O2, and to the earlobes, A1 and A2, which were electrically paralleled. The electrode impedance was always less than 10,000 ohms. Four EEG data channels are recorded: Channel 1 = Pz-A, Channel 2 = Oz-Pz, Channel 3 = O1-Pz, and Channel 4 = O2-Pz. A lead is taken from Fpz-Oz and used to scan for artifacts such as those caused by eyeblinks or excessive subject movement; if a peak to peak deflection occurs in this channel which exceeds a parameter level, the data epoch is aborted.

EEG signals are amplified over a bandwidth of 1.0 to 70 Hertz and digitized at 4 millisecond intervals. A data epoch consists of samples taken both before (400 to 960 msec) and after (320 msec) the stimulus.

STIMULI consisted of unpatterned colored flashes of light, for the color experiment, superimposed on a background light which was yellow and of 100 NITS luminance(0.01 lamberts) .Four colors

were generated by interference filters with peak transmission wavelengths at 465 nm. (blue), 515 nm. (green), 575 nm. (yellow), and 620 nm. (red). The yellow background light was generated by the use of a Wratten filter #4 and a 60 watt incandescent bulb operated at 60 volts by a Variac.

The color flashes were brief (30 microsecond) pulses of 6000 degree Kelvin Xenon strobe light. The interference filters were nearly isoenergetic when checked with a spectrophotometer, but the slightly blue color temperature of the Xenon strobe was not corrected. The intensity of the light stimuli was 10 exp 7 lux in a collimated beam entering the interference filters. The attenuation due to the color filters was about 1.3 log units.

3.1.2 Analysis

Data analysis is performed either on a SDS 930 computer, or on the campus IBM 360/91. Stepwise discriminant analysis (SDA) is used to develop four linear discriminant functions (one for each of the four color classes) which then are evaluated for each epoch in order to calculate the posteriori probability of belonging to each group.

For this report, the SDA routine was run repeatedly on each subject in order to choose a more optimal subset of variables for use in the discriminant functions. In order to accomplish this, the samples were entered into runs in time slices; variables 11 through 20 were taken for each of four EEG channels for the first run, then samples 21 to 30, 31 to 40, 41 to 50, 51 to 60, 61 to 70, and 71 to 80 . Each 40 variable run would go at most 10 steps, so the result of the seven SDA runs is to produce a list of at most 70 variables, and their F levels. From this list ,

the variables with the highest 40 F levels were chosen to go into a final SDA run. The first 100 epochs are taken for the training set, which is used to calculate the DF's. The second 100 epochs then are entered as a testing set of data.

The results of these SDA runs on the ten color evoked response subjects are shown in Table I.

Table I

RESULTS OF COLOR EVOKED RESPONSE EXPERIMENTS - SUMMARY TABLE

Subject	Date	Expr.	Training set perform. Mutual Info.	% Correct	Testing set perform. Mutual Info.	% Correct.
SB01	MR13	OC4G	1.9058	99.0	1.6334	93.8
SB01	MR13	OC43 S	1.6173	92.7	1.6273	92.7
SAG1	MR27		1.9874	100	1.5299	90.6
SAD1	AP03	G	1.6483	93.8	1.0425	79.2
ATW1	AP17		1.7904	95.8	1.1100	79.2
SOS1	AP15		1.8547	97.9	1.0135	78.1
SAG1	MR27	G	1.6530	93.8	1.2432	77.1
NLM1	AP08	G	1.8236	96.9	1.0513	76.0
MHD1	AP15		1.4041	88.5	0.7770	67.7
ALL1	MR25	OC41 G	1.6924	94.8	0.5761	64.6
ALL1	MR25	OC42 S	1.3085	86.5	0.3825	56.3
JMS1	AP10	G	1.2596	85.4	0.3004	50.0
APN1	MR19		1.1817	83.3	0.2137	45.8

These results were obtained in first half / second half training/testing set runs of BCISDA using recursive analyses to find tailored sample windows. Every sample in the data set (except for the first 10 samples following the stimulus) had an opportunity to be selected by this procedure.

3.1.3 CONTRIBUTIONS

In order to ascertain the contribution of each variable to a given group discriminant function (D.F.) the following procedure is adopted, as suggested by Tatsuoka (1971); The coefficients of the variables in the Discriminant Functions are a first approximation to the degree of contribution each variable provides (on the average) to classification of the given group, but these values need correction by a factor (Vi*) which can be obtained in the following manner;

Vi* squared = Vi/d.f., where the Vi are the diagonals of the residuals (variances) in the variance-covariance matrix, d.f. is the number of degrees of freedom associated with the Vi (d.f.=# of epochs-1). Each coefficient in the D.F. is then multiplied by Vi*. Then, for a given experiment, these products are normalized to a maximum of 100 for easy comparison. These Contributions are tabulated in Tables 2 to 7, for the six subjects who gave the best performance in terms of percent of epochs correctly classified.

TABLE 2 CONTRIBUTIONS
SUBJECT:SB01

CH	Time	F	R	Red	Yellow	Green	Blue
1	120ms	12.6	4	28	2	5	10
3	76	156.0	1	100	11	24	27
3	104	11.8	6	1	19	10	15
3	120	35.2	2	20	23	1	22
3	156	21.7	3	61	2	29	27
4	100	12.1	5	18	15	3	10

Performance with 6 step DF

	%	M.I.
Train	93.8	1.65
Test	90.0	1.56

TABLE 3 CONTRIBUTIONS
SUBJECT:SA01

CH	Time	F	R	Red	Yellow	Green	Blue
2	80ms	23.5	3	70	8	20	26
2	136	26.5	2	100	53	24	51
2	172	17.1	4	11	28	33	4
2	320	10.8	6	29	19	2	44
3	136	13.0	5	45	48	29	51
4	96	28.2	1	53	6	37	27

Performance with 6 step DF

	%	M.I.
Train	88.5	1.41
Test	82.0	1.13

TABLE 4 CONTRIBUTIONS
SUBJECT:NLA1

CH	Time	F	R	Red	Yellow	Green	Blue
1	80ms	31.0	1	100	10	26	38
1	88	16.5	6	93	24	3	58
2	76	30.3	2	53	4	35	1
2	84	20.0	4	25	28	3	8
2	96	30.1	3	73	11	7	30
2	200	18.5	5	13	19	4	4

Performance with 6 step DF

	%	M.I.
Train	93.8	1.69
Test	71.0	0.99

TABLE 5 CONTRIBUTIONS
SUBJECT:SADT

CH	Time	F	R	Red	Yellow	Green	Blue
1	112ms	17.0	4	52	26	10	100
1	124	24.0	2	31	29	25	64
1	144	23.2	3	25	44	31	3
2	84	11.4	6	53	3	1	23
2	100	29.5	1	76	15	3	69
2	160	14.4	5	28	26	8	0

Performance with 6 step DF

	%	M.I.
Train	83.3	1.16
Test	70.0	0.73

TABLE 6 CONTRIBUTIONS
SUBJECT:ATWT

CH	Time	F	R	Red	Yellow	Green	Blue
2	96ms	7.8	5	15	5	34	35
2	112	20.3	1	28	61	100	16
2	132	17.3	2	44	36	34	36
2	196	11.4	4	67	23	18	3
3	88	7.4	6	11	41	7	38
4	112	13.6	3	13	49	80	19

Performance with 6 step DF

	%	M.I.
Train	79.2	1.07
Test	70.0	0.70

TABLE 7 CONTRIBUTIONS
SUBJECT:SOST

CH	Time	F	R	Red	Yellow	Green	Blue
1	76ms	13.3	3	3	25	8	1
2	80	74.8	1	100	15	27	29
2	132	10.4	4	34	19	8	14
2	248	10.1	5	30	19	19	7
3	34	35.2	2	93	33	22	22
3	104	8.3	6	5	2	16	0

Performance with 6 step DF

	%	M.I.
Train	81.3	1.24
Test	51.0	0.73

3.2 PATTERN=POSITION EXPERIMENTS

In order to test the probable effect of adding a cathode ray tube (CRT) display to the stimulus array, in place of the background lamp, three subjects were tested in the pattern-position experiment, while varying the intensity of the background lamp. A variac was used to adjust the voltage to the lamp. 60 volts was the standard high setting (100 NITS luminance), and 40 volts provided a low intensity (1 NIT luminance) to simulate the effect of a CRT display. In the same series of experiments, two sizes of checkerboard stimuli were tested; the original 2.2 degree visual angle display, and a larger 4.4 degree display. The classification performance achieved is given in Table 8.

Table 8

CLASSIFICATION PERFORMANCE VS DISPLAY SIZE, ILLUMINATION

SUBJ.	EXPR.	CB Size	BG Int.	% Correct
SAD2	CB41	Small	High	72
	CB42	Small	Low	75
	CB43	Large	High	35
	CB44	Large	Low	85
SOG2	CB41	Small	High	73
	CB42	Small	Low	68
SAG2	CB41	Large	High	56
	CB42	Large	Low	61
	CB43	Small	Low	55
	CB44	Small	High	63

Referring to Table 8, it can be seen that with subject SAG2, variations in background illumination or checkerboard size had little effect. The large checkerboard proved to be better for subject SAD2, while background luminance had little effect. With subject SOG2 the normal (high) background gave slightly better

results than a low background. The 4.4 degree stimulus evoked larger scalp potentials than the 2.2 degree stimulus; the negative polarity 120 to 130 millisecond peak seen in subject SAD2, channel 1 (Oz-A) after the "UP" stimulus was 2.5 uV and 3 uV (High and Low background, respectively) with the 2.2 degree field and 4uV and 4.5uV with the 4.4 degree field. The effect of decreasing the background light was to increase the retinal gain and thus increase slightly (10 to 15%) the amplitude of the evoked response.

It appears that the replacement of the background light with a CRT display would not degrade the visual evoked responses significantly.

The larger 4.4 degree checkerboard did perform significantly better than did the original 2.2 degree stimulus, so the larger one was used for all subsequent experimentation.

MAZE EXPERIMENT

In order to demonstrate the performance of the online evoked response classifying system, it was decided to incorporate a robot "mouse" in a computer generated maze as an integral part of the system display.

A diagram of the maze is illustrated in Figure 1 (Appendix). The mouse starts at node 1, and the subjects task is to command the mouse to move one jump at a time through the maze by the shortest path to the cheese, at node 11. The input alphabet of commands necessary to accomplish this task consists of the following four: UP, DOWN, LEFT, RIGHT. The commands are selected by the subject by directing the gaze at one of the four LED fixation points arrayed at the vertices of the stimulus display. The mouse is

displayed in the maze on a CRT which constitutes one field of the two field stimulus display. When the checkerboard display is briefly illuminated by a strobe, under computer control, it appears briefly to the subject superimposed upon the maze display.

ONLINE EVOKED RESPONSE CLASSIFICATION

The NASA-type EEG helmet was used for the following two experiments. SAD4 was run as an offline simulation, with a classification performance of 82% correct. SAD5 constituted the first successful online evoked response classification; the subject was able to command the robot mouse to move through the maze with relative ease, using the visual light pen scheme. Overall performance on this run was 76% correct.

A major milestone has been reached, online evoked response classification has been achieved. .

The detailed plots of average evoked responses, online outputs from SDA, and theoretical considerations for Bayesian classification and mutual information transfer are contained in the Appendix.

4. APPENDIX

The appendix contains Figure 1, the Maze diagram, and the online results from experiments SAD4 and SAD5.

The appendix also contains plots of average evoked potentials to color stimuli for six subjects. The averages are of 50 epochs per color, four colors, for 200 epochs total. The numbered arrows on the plots mark the time samples which were selected by the SDA program as the best discriminators. The six samples with the highest F levels of the ten samples selected are marked, and their number refers to their F level rank (1 is the highest, 6 is the lowest). The SDA training set was the first 96 epochs, whereas all 200 epochs are plotted. The last 100 epochs were the testing sets.

The next plotted averages are for the pattern-position experiment. Similarly, the best six of ten samples are marked with arrows and numbered according to the F level ranks.

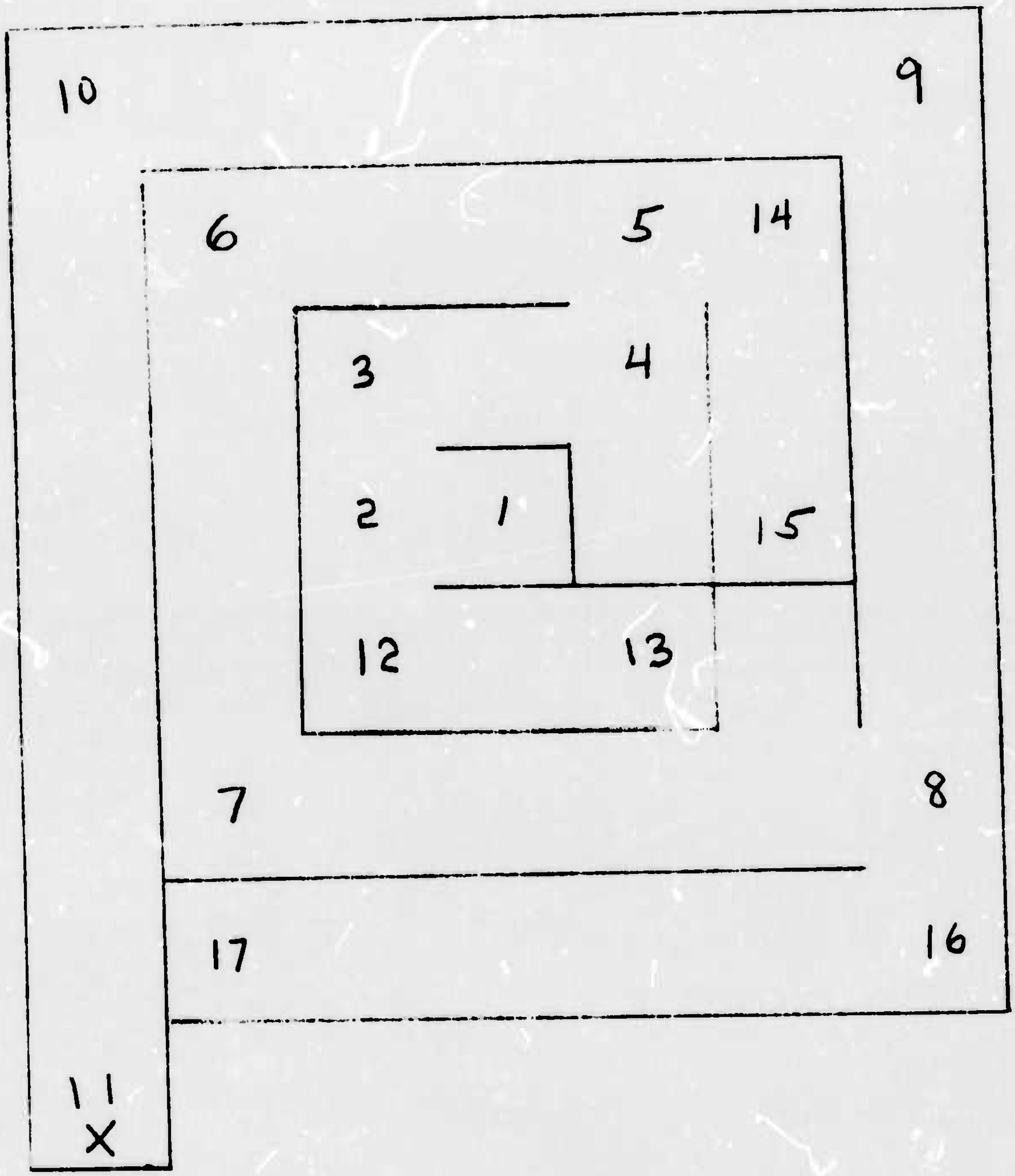


FIG. 1

ON-LINE

CLASSIFICATION

$$p(w_i|X) = \frac{p(w_i)\ p(X|w_i)}{\sum_j p(w_j)\ p(X|w_j)}\ .$$

$$p(X|w_i) = \frac{\exp\left[-0.5\ (X-U_i)^t\ S_i^{-1}\ (X-U_i)\right]}{(2\pi)^d\ |S|^{1/2}}$$

$$p(w_i|X) = \frac{p(w_i)\ \exp\ -0.5\ U_i^t S_i^{-1} U_i + U_i^t S^{-1} X}{\sum_j p(w_j)\ \exp\left[-0.5\ U_j^t S^{-1} U_j + U_j^t S^{-1} X\right]}$$

PERFORMANCE

MEASUREMENT

$$\text{Mutual Information} = \text{Received Entropy} - \text{Received Equivocation}$$

$$\text{Received Entropy} = \sum_{B} p(b) \ln \left[\frac{1}{p(b)} \right]$$

$$\text{Received Equivocation} = \sum_{A} p(a) \sum_{B} p(b|a) \ln \left[\frac{1}{p(b|a)} \right]$$

$$p(b) = \sum_{A} p(a)\ p(b|a)$$

$$\text{Mutual Information} = \sum_{A} p(a) \sum_{B} p(b|a) \ln \left[\frac{p(b|a)}{\sum_{A} p(a)\ p(b|a)} \right]$$

STEPWISE DISCRIMINANT ANALYSIS

SAD4-JN18-75-0 PATTERN

RECURSION = 1

DATA SET IDENTIFIERS:

F LEVEL TO ENTER = 2.200

NO. OF DATA = 100

F LEVEL TO REMOVE = 2.200

WGT. D.O.F. = 100.0C

F LEVEL OF VARIABLES, D.O.F. = 3.0, 96.0

VARIABLE INDEX	NAME	F LEVEL
1	1,020	9.766061
2	1,025	3.711718
3	1,030	35.548014
4	1,035	9.070506
5	1,040	.629859
6	1,045	.892756
7	1,050	2.912513
8	1,055	1.272461
9	2,020	1.771619
10	2,025	5.344451
11	2,030	7.426393
12	2,035	10.089318
13	2,040	6.364830
14	2,045	3.172332
15	2,050	1.215869
16	2,055	4.302918
17	3,020	3.480814
18	3,025	30.412805
19	3,030	9.675748
20	3,035	11.825252
21	3,040	27.628447
22	3,045	5.783466
23	3,050	2.411817
24	3,055	7.773142
25	4,020	9.089666
26	4,025	17.949392
27	4,030	5.238561
28	4,035	27.327971
29	4,040	28.063357
30	4,045	8.151955
31	4,050	2.825919
32	4,055	4.687158
33	5,020	9.675697
34	5,025	14.316160
35	5,030	33.365011
36	5,035	4.954664
37	5,040	1.752939
38	5,045	6.157046
39	5,050	.557396
40	5,055	5.315046

SAD4-JN18-75-0 PATTERN EXPERIMENT 5 CHANNELS WIDE GENERAL WINDOW

DISCRIMINANT FUNCTIONS AFTER 10 STEPS, WITH D.O.F. = 3.0, 87.(

EPOCHS ACCEPTED UNCONDITIONALLY.

VARIABLE INDEX	NAME	F LEVEL	UP	DOWN	LEFT	RIGHT
3	1,030	.15682E 02	-.26814E-01	.14359E-02	-.91716E-02	-.14896E-01
18	3,025	.93409E 01	.20395E-01	.63263E-02	.26941E-01	.70659E-02
19	3,030	.37238E 01	.34340E-02	-.72899E-02	-.19233E-02	.10476E-01
21	3,040	.77144E 01	-.24253E-02	-.96980E-03	-.10359E-01	.15176E-01
22	3,045	.27873E 01	.12972E-02	-.52925E-03	-.97816E-02	.90792E-02
24	3,055	.71477E 01	-.11393E-01	.22786E-01	-.72999E-03	-.35367E-02
28	4,035	.12088E 02	-.32905E-01	-.51839E-02	-.47860E-02	-.33267E-01
34	5,025	.44858E 01	.14232E-01	-.41469E-02	.11776E-01	.13752E-01
35	5,030	.13226E 02	.20110E-01	-.11750E-01	.11858E-01	.85444E-02
40	5,055	.85215E 01	-.13819E-01	.16827E-01	.16431E-02	-.83356E-02
CONSTANT			-.13866E 02	-.51323E 01	-.83885E 01	-.89523E 01
APRIORI PROBABILITY			.25000E 00	.25000E 00	.25000E 00	.25000E 00

TRAINING CONFUSION MATRIX IEPA = 1 NEPI = 100 IEPS = 2

PT= 0.8

SOURCE	PERCENT CORRECT	MUTUAL INFORM.	UP	DOWN	LEFT	RIGHT	DEFAULT
UP	100.0	1.7066	19.0	.0	.0	.0	6.0
DOWN	100.0	1.8477	.0	24.0	.0	.0	1.0
LEFT	100.0	1.7333	.0	.0	22.0	.0	3.0
RIGHT	100.0	1.7108	.0	.0	.0	21.0	4.0
TOTAL	100.0	1.7496					

TRAINING CONFUSION MATRIX IEPA = 1 NEPI = 100 IEPS = 2

PT= 0.6

SOURCE	PERCENT CORRECT	MUTUAL INFORM.	UP	DOWN	LEFT	RIGHT	DEFAULT
UP	95.2	1.5491	20.0	.0	.0	1.0	4.0
DOWN	100.0	1.8800	.0	24.0	.0	.0	1.0
LEFT	100.0	1.8400	.0	.0	23.0	.0	2.0
RIGHT	91.7	1.5468	2.0	.0	.0	22.0	1.0
TOTAL	96.7	1.7040					

TRAINING CONFUSION MATRIX IEPA = 1 NEPI = 100 IEPS = 2

PT= 0.4

SOURCE	PERCENT CORRECT	MUTUAL INFORM.	UP	DOWN	LEFT	RIGHT	DEFAULT
UP	92.0	1.5004	23.0	.0	.0	2.0	.0
DOWN	100.0	2.0000	.0	25.0	.0	.0	.0
LEFT	96.0	1.8098	1.0	.0	24.0	.0	.0
RIGHT	88.0	1.5091	3.0	.0	.0	22.0	.0
TOTAL	94.0	1.7048					

SAD 4

TESTING CONFUSION MATRIX IEPT = 2 NEPI = 100 IEPS = 2 P

PT= 0.8

OURCE	PERCENT CORRECT	MUTUAL INFORM.	CLASSIFIED AS UP	DOWN	LEFT	RIGHT	DEFAULT
UP	75.0	1.0486	15.0	.0	1.0	4.0	5.0
DOWN	95.5	1.5048	.0	21.0	.0	1.0	3.0
LEFT	100.0	1.4044	.0	.0	20.0	.0	5.0
IGHT	84.2	.9898	.0	.0	3.0	16.0	6.0
OTAL	88.9	1.2369					

TESTING CONFUSION MATRIX IEPT = 2 NEPI = 100 IEPS = 2 P

PT= 0.6

OURCE	PERCENT CORRECT	MUTUAL INFORM.	CLASSIFIED AS UP	DOWN	LEFT	RIGHT	DEFAULT
UP	73.9	1.0804	17.0	.0	1.0	5.0	2.0
DOWN	87.5	1.3993	.0	21.0	2.0	1.0	1.0
LEFT	91.3	1.2910	2.0	.0	21.0	.0	2.0
IGHT	87.0	1.1722	.0	.0	3.0	20.0	2.0
OTAL	84.9	1.2357					

TESTING CONFUSION MATRIX IEPT = 2 NEPI = 100 IEPS = 2 P

PT= 0.4

OURCE	PERCENT CORRECT	MUTUAL INFORM.	CLASSIFIED AS UP	DOWN	LEFT	RIGHT	DEFAULT
UP	72.0	.9924	18.0	.0	2.0	5.0	.0
DOWN	84.0	1.4112	.0	21.0	3.0	1.0	.0
LEFT	88.0	1.2613	3.0	.0	22.0	.0	.0
IGHT	84.0	1.1184	1.0	.0	3.0	21.0	.0
OTAL	82.0	1.1958					

TESTING CONFUSION MATRIX IEPT = 2 NEPI = 100 IEPS = 2 P

PT= 0.25

OURCE	PERCENT CORRECT	MUTUAL INFORM.	CLASSIFIED AS UP	DOWN	LEFT	RIGHT	DEFAULT
UP	72.0	.9924	18.0	.0	2.0	5.0	.0
DOWN	84.0	1.4112	.0	21.0	3.0	1.0	.0
LEFT	88.0	1.2613	3.0	.0	22.0	.0	.0
IGHT	84.0	1.1184	1.0	.0	3.0	21.0	.0
OTAL	82.0	1.1958					

COMPLETED 10 STEPS OF ANALYSIS

STEPWISE DISCRIMINANT ANALYSIS — SAD5-JN19-75-0 PATTERN E:

RECURSION = 1 — DATA SET IDENTIFIERS: E:

F LEVEL TO ENTER = 2.200 — NO. OF DATA = 100

F LEVEL TO REMOVE = 2.200 — WGT. D.O.F. = 100.00

F LEVEL OF VARIABLES, D.O.F. = 3.0, 96.0

VARIABLE INDEX	VARIABLE NAME	F LEVEL
1	1,020	13.485518
2	1,025	17.009837
3	1,030	33.075112
4	1,035	2.659483
5	1,040	1.315708
6	1,045	1.263415
7	1,050	8.196180
8	1,055	20.983862
9	2,020	1.418554
10	2,025	5.307304
11	2,030	4.230269
12	2,035	1.696842
13	2,040	1.779694
14	2,045	4.126825
15	2,050	.306714
16	2,055	1.102535
17	3,020	6.031110
18	3,025	22.418901
19	3,030	16.309053
20	3,035	18.875936
21	3,040	6.897306
22	3,045	1.221283
23	3,050	3.099672
24	3,055	5.862851
25	4,020	8.853769
26	4,025	4.258303
27	4,030	22.376233
28	4,035	14.265531
29	4,040	19.598626
30	4,045	8.347433
31	4,050	1.329457
32	4,055	5.822729
33	5,020	21.820222
34	5,025	29.977412
35	5,030	39.636334
36	5,035	1.640686
37	5,040	4.481712
38	5,045	3.398246
39	5,050	8.443925
40	5,055	18.226396

SAD5-JN19-75-0 PATTERN EXPERIMENT 5 CHANNELS WIDE GENERAL WINDOW

DISCRIMINANT FUNCTIONS AFTER 10 STEPS, WITH D.O.F. = 3.0, 87.0

EPOCHS ACCEPTED UNCONDITIONALLY.

VARIABLE DEX	NAME	F LEVEL	GROUP NAMES UP	DOWN	LEFT	RIGHT
1	2,030	.41818E 01	.11106E 00	.35220E-01	.81780E-01	.68432E-01
5	2,050	.57813E 01	-.97677E-02	.73871E-01	.31674E-01	.38847E-01
0	3,035	.96830E 01	-.10250E-01	.61206E-03	-.24258E-01	-.16553E-02
7	4,030	.14932E 02	-.68552E-02	-.14715E-01	-.33248E-02	-.23932E-01
9	4,040	.10265E 02	-.24236E-01	.11391E-01	-.12860E-02	-.10303E-01
0	4,045	.58562E 01	.11874E-01	.30012E-03	.23718E-01	.11310E-01
3	5,020	.71038E 01	-.70435E-02	.73535E-02	-.80218E-02	-.23842E-02
4	5,025	.10106E 02	.38536E-02	-.86153E-02	.31943E-02	.36852E-02
5	5,030	.17748E 02	.26896E-01	-.65272E-02	.12961E-01	.76221E-02
9	5,050	.16141E 02	-.10905E-01	.25955E-01	.74304E-02	.10246E-01
CONSTANT			-.11767E 02	-.10987E 02	-.91997E 01	-.91542E 01

			UP	DOWN	LEFT	RIGHT
PRIORI PROBABILITY			.25000E 00	.25000E 00	.25000E 00	.25000E 00

POSTERIORI PROBABILITY FROM GROUP -

EPOCH 10.	SUMMARY GROUP	CHOICE	GROUP NAMES UP	DOWN	LEFT	RIGHT
1	RIGHT		.00000	.11828	.00045	.88126
2	UP		.91995	.00000	.07911	.00094
3	DOWN	LEFT	.00000	.46870	.52330	.00800
5	LEFT		.01220	.00000	.98539	.00241
6	UP		.99966	.00000	.00003	.00031
1	DOWN		.00000	1.00000	.00000	.00000
2	LEFT		.00113	.00174	.61649	.38064
5	RIGHT		.00096	.00483	.01020	.98401
6	LEFT		.00015	.00647	.58830	.40508
7	DOWN		.00000	.99996	.00000	.00003
9	UP		.95729	.00000	.03533	.00737
20	RIGHT		.00004	.00007	.00099	.99890
24	DOWN		.00000	.99996	.00003	.00001
26	LEFT		.00006	.00078	.99882	.00035
28	DOWN		.00000	.99999	.00001	.00001
29	RIGHT		.00106	.00000	.00006	.99887
30	UP		.99905	.00000	.00092	.00003
32	LEFT		.03263	.00001	.95057	.01679
34	LEFT	RIGHT	.00075	.14241	.39970	.45714
37	LEFT		.00043	.00003	.96328	.03625
39	RIGHT		.00082	.00184	.04065	.95669
42	LEFT		.00301	.00000	.99690	.00009
43	DOWN		.00000	.99857	.00000	.00142
45	UP		.99961	.00000	.00011	.00028
48	DOWN		.00000	.99996	.00000	.00004
49	LEFT		.00427	.00000	.99544	.00029
50	UP		.99753	.00000	.00005	.00242

SAD 5 CB4T

TRAINING CONFUSION MATRIX IEPA = 1 NEPI = 100 IEPS = 2

P.T.= 0.8

SOURCE	PERCENT CORRECT	MUTUAL INFORM.	CLASSIFIED AS UP	DOWN	LEFT	RIGHT	DEFAULT
UP	100.0	1.8032	23.0	.0	.0	.0	2.0
DOWN	95.7	1.6249	.0	22.0	.0	1.0	2.0
LEFT	100.0	1.7101	.0	.0	21.0	.0	4.0
RIGHT	95.5	1.5403	.0	.0	1.0	21.0	3.0
TOTAL	97.8	1.6696					

TRAINING CONFUSION MATRIX IEPA = 1 NEPI = 100 IEPS = 2

PT = 0.6

SOURCE	PERCENT CORRECT	MUTUAL INFORM.	CLASSIFIED AS UP	DOWN	LEFT	RIGHT	DEFAULT
UP	100.0	1.8312	24.0	.0	.0	.0	1.0
DOWN	95.8	1.7093	.0	23.0	.0	1.0	1.0
LEFT	100.0	1.7969	.0	.0	22.0	.0	3.0
RIGHT	91.3	1.4323	1.0	.0	1.0	21.0	2.0
TOTAL	96.8	1.6924					

TRAINING CONFUSION MATRIX IEPA = 1 NEPI = 100 IEPS = 2

PT= 0.4

SOURCE	PERCENT CORRECT	MUTUAL INFORM.	CLASSIFIED AS UP	DOWN	LEFT	RIGHT	DEFAULT
UP	96.0	1.7512	24.0	.0	1.0	.0	.0
DOWN	92.0	1.6243	.0	23.0	1.0	1.0	.0
LEFT	96.0	1.6031	.0	.0	24.0	1.0	.0
RIGHT	88.0	1.3992	1.0	.0	2.0	22.0	.0
TOTAL	93.0	1.5944					

TESTING CONFUSION MATRIX IEPT = 2 NEPI = 100 IEPS = 2

PT= 0.8

SOURCE	PERCENT CORRECT	MUTUAL INFORM.	CLASSIFIED AS UP	DOWN	LEFT	RIGHT	DEFAULT
UP	90.5	1.3627	19.0	.0	2.0	.0	4.0
DOWN	100.0	1.5611	.0	22.0	.0	.0	3.0
LEFT	100.0	1.4665	.0	.0	18.0	.0	7.0
RIGHT	89.5	1.2963	.0	2.0	.0	17.0	6.0
TOTAL	95.0	1.4217					

TESTING CONFUSION MATRIX IEPT = 2 NEPI = 100 IEPS = 2

PT= 0.6

SOURCE	PERCENT CORRECT	MUTUAL INFORM.	CLASSIFIED AS UP	DOWN	LEFT	RIGHT	DEFAULT
UP	83.3	1.2562	20.0	.0	3.0	1.0	1.0
DOWN	100.0	1.7963	.0	24.0	.0	.0	1.0
LEFT	91.3	1.3731	1.0	.0	21.0	1.0	2.0
RIGHT	87.5	1.3225	1.0	2.0	.0	21.0	1.0
TOTAL	90.5	1.4370					

TESTING CONFUSION MATRIX IEPT = 2 NEPI = 100 IEPS = 2

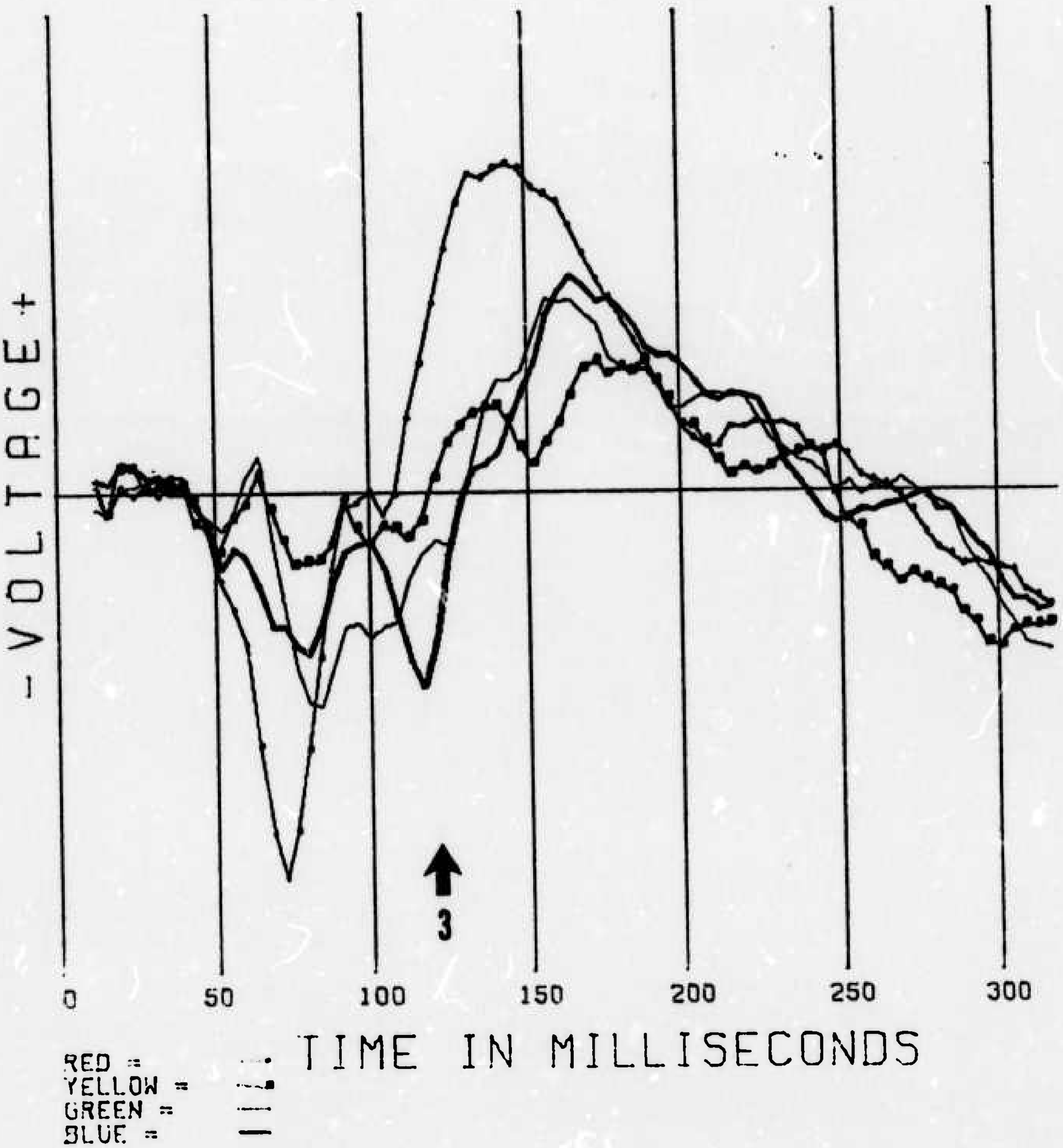
PT= 0.4

SOURCE	PERCENT CORRECT	MUTUAL INFORM.	CLASSIFIED AS UP	DOWN	LEFT	RIGHT	DEFAULT
UP	84.0	1.2382	21.0	.0	3.0	1.0	.0
DOWN	96.0	1.7034	.0	24.0	1.0	.0	.0
LEFT	84.0	1.2104	2.0	.0	21.0	2.0	.0
RIGHT	84.0	1.2506	2.0	2.0	.0	21.0	.0
TOTAL	87.0	1.3507					

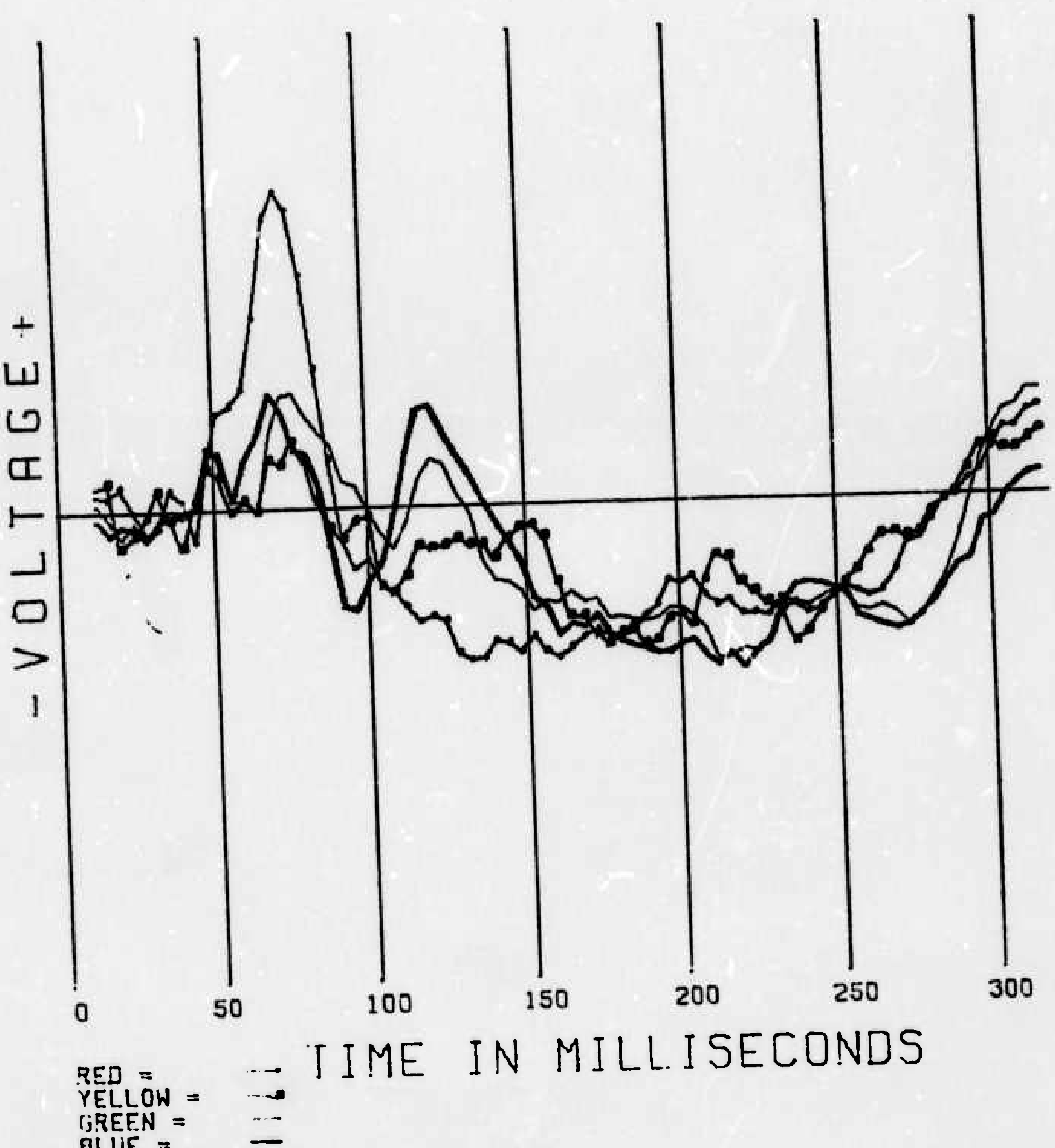
The following table is a blow by blow account of the first on-line maze control run. In this first run, 24 moves were required to run the mouse through the maze to the cheese. The columns on the right give the posteriori probability that each command belongs to the group UP, DOWN, LEFT, RIGHT. When the probability was less than the posteriori threshold of 0.6, the epoch was defaulted. Two commands were defaulted, which meant that the mouse did not move on those epochs.

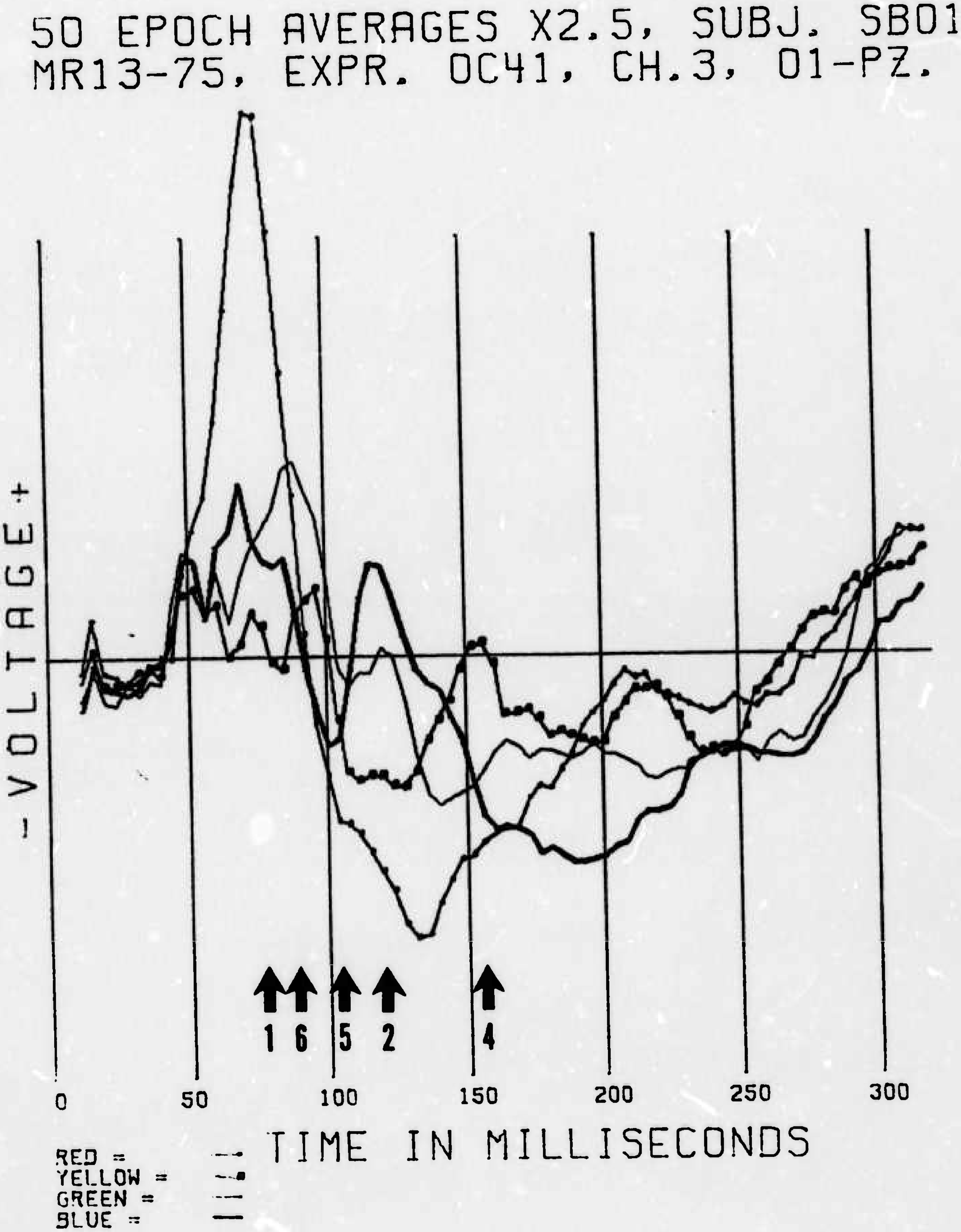
					UP	DOWN	LEFT	RIGHT
EPOCH	1	[A 2]	IS CLASSED AS 3	LEFT	.00000	.09229	.90685	.00086
EPOCH	2	[A 3]	IS CLASSED AS 1	UP	.99952	.00000	.00004	.00044
EPOCH	3	[A 4]	IS CLASSED AS 2	DOWN	.00001	.72063	.03076	.24860
EPOCH	4	[A 5]	IS CLASSED AS 1	UP	.98554	.00000	.01439	.00007
EPOCH	5	[A 6]	IS CLASSED AS 4	RIGHT	.00000	.00039	.00000	.99960
EPOCH	6	[A 7]	IS CLASSED AS 3	LEFT	.02232	.00000	.64453	.33315
EPOCH	7	[A 8]	IS CLASSED AS 1	U	.99501	.00000	.00081	.00418
EPOCH	8	[A 9]	IS CLASSED AS 4	R	.00000	.09035	.00374	.90591
EPOCH	9	[A10]	IS CLASSED AS 1	U	.98534	.00000	.01055	.00411
EPOCH	10	[A11]	IS CLASSED AS 3	L	.00003	.01765	.96482	.01751
EPOCH	11	[A12]	IS CLASSED AS 3	L	.00092	.14388	.85286	.00234
EPOCH	12	[A13]	IS CLASSED AS 3	L	.00007	.00000	.94769	.05224
EPOCH	13	[A14]	IS CLASSED AS 0	DEF.	.00001	.41598	.44421	.13980
EPOCH	14	[A15]	IS CLASSED AS 4	R	.00091	.03325	.00474	.96110
EPOCH	15	[A16]	IS CLASSED AS 3	L	.00017	.00001	.99930	.00052
EPOCH	16	[A17]	IS CLASSED AS 2	D	.00000	1.00000	.00000	.00000
EPOCH	17	[A18]	IS CLASSED AS 4	R	.00199	.00000	.00011	.99789
EPOCH	18	[A19]	IS CLASSED AS 0	DEF.	.00001	.10511	.42648	.46841
EPOCH	19	[A20]	IS CLASSED AS 1	U	.99700	.00000	.00015	.00285
EPOCH	20	[A21]	IS CLASSED AS 4	R	.00204	.13895	.15521	.70380
EPOCH	21	[A22]	IS CLASSED AS 1	U	.87448	.00000	.00030	.12522
EPOCH	22	[A23]	IS CLASSED AS 3	L	.00056	.00000	.99944	.00000
EPOCH	23	[A24]	IS CLASSED AS 3	L	.00010	.19792	.73774	.06425
EPOCH	24	[A25]	IS CLASSED AS 2	DOWN	.00000	1.00000	.00000	.00000

50 EPOCH AVERAGES X2.5, SUBJ. SB01
MR13-75, EXPR. OC41, CH.1, PZ-A.



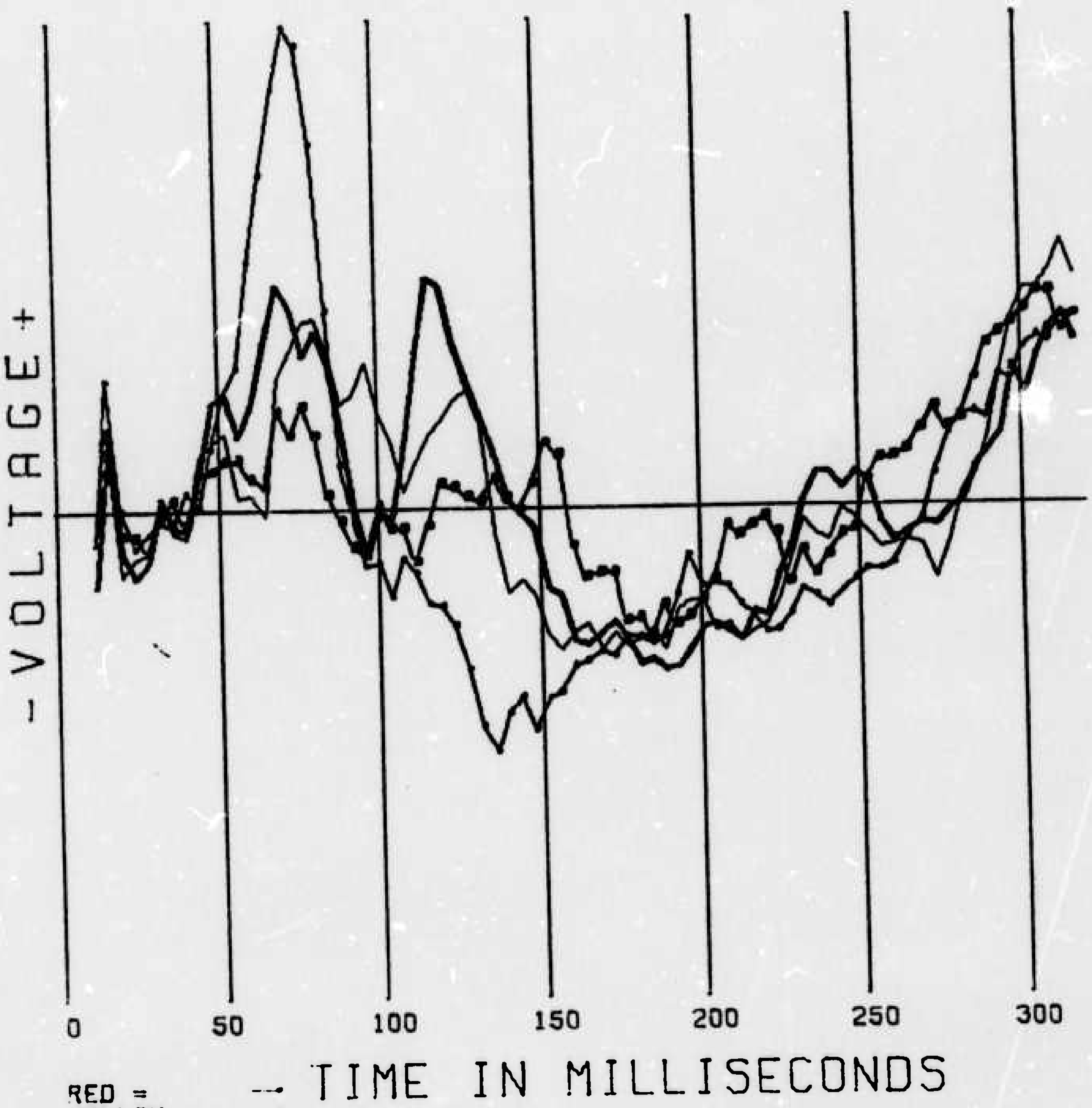
50 EPOCH AVERAGES X2.5, SUBJ. SB01
MR13-75, EXPR. OC41, CH.2, OZ-PZ.



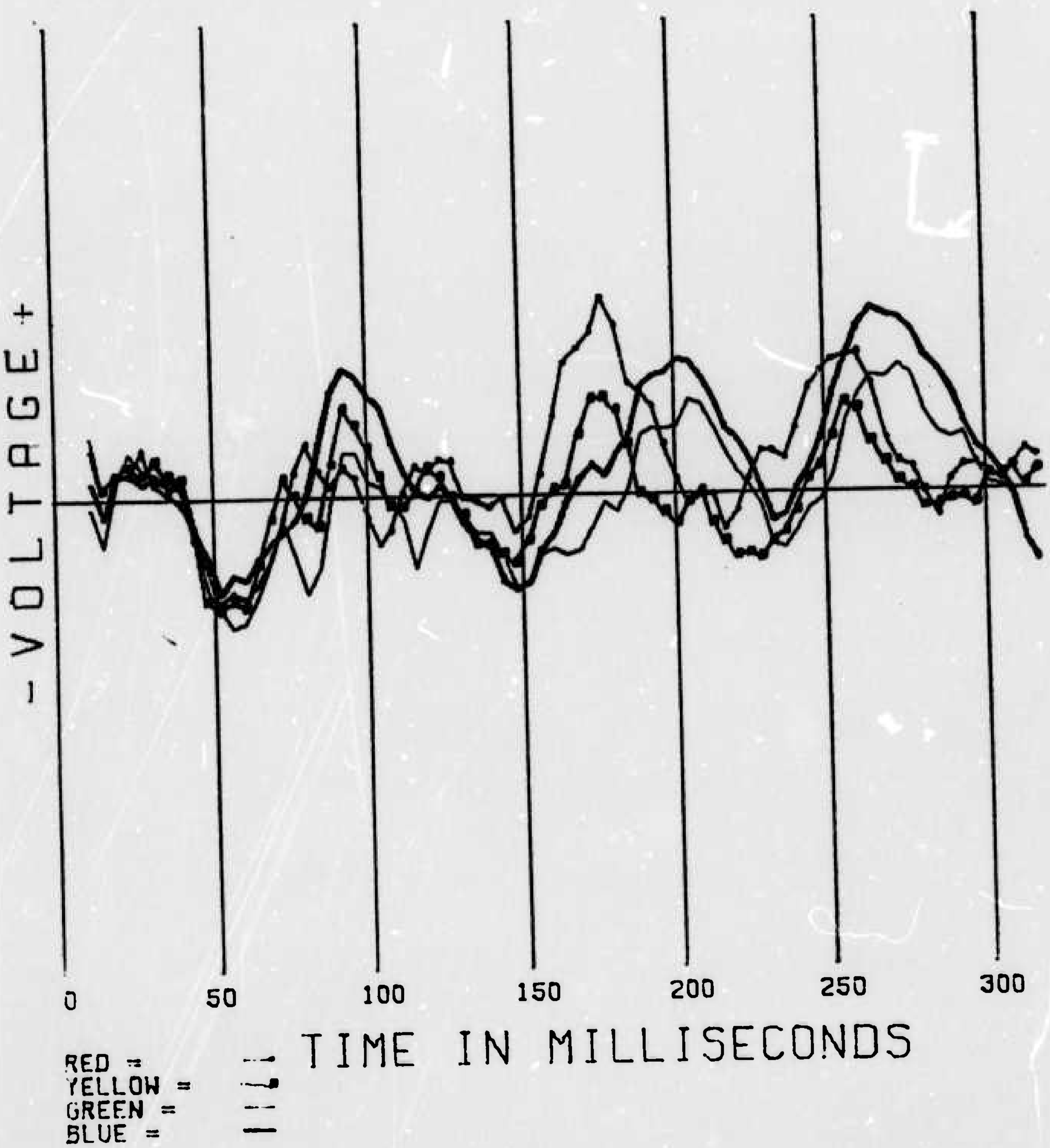


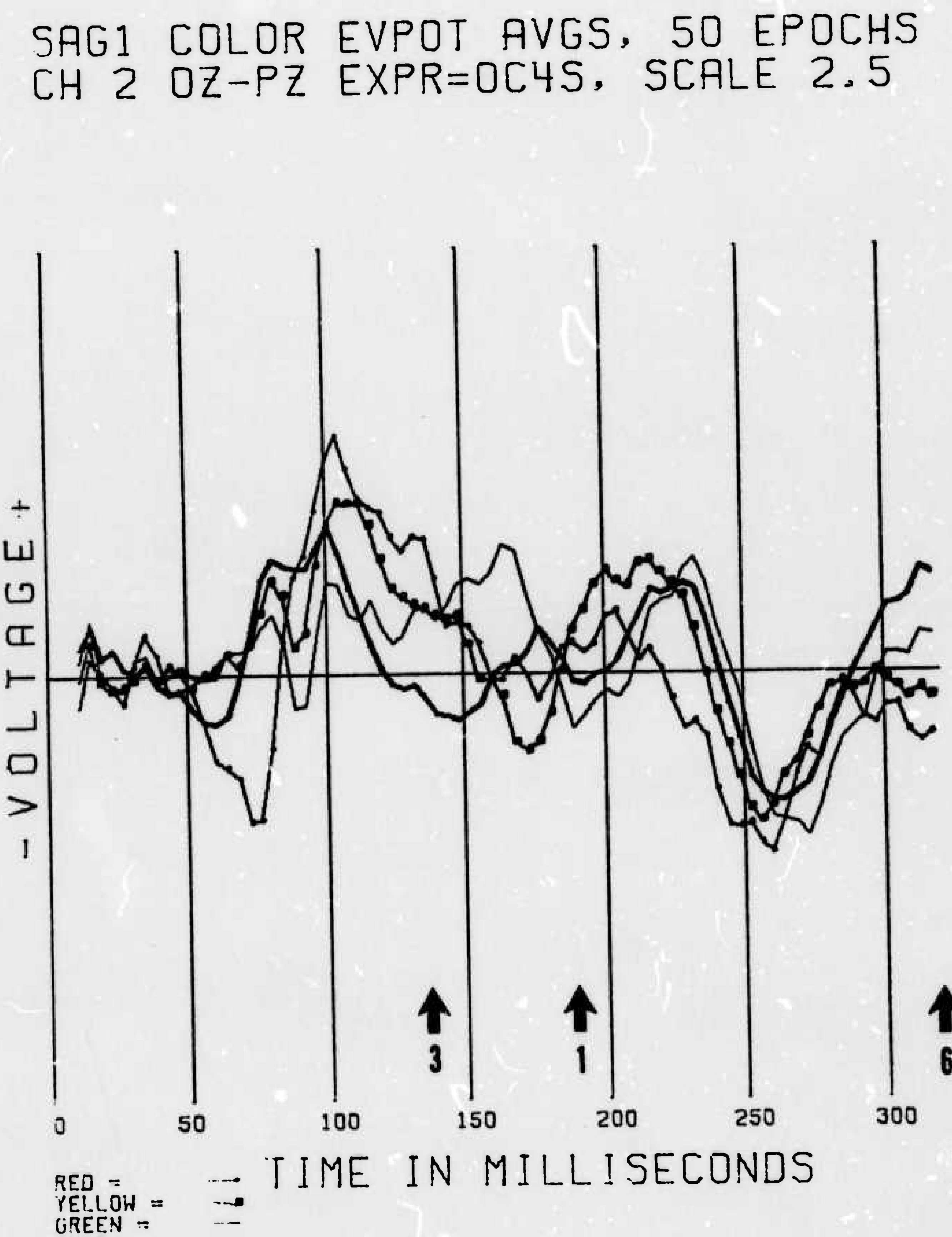
50 EPOCH AVERAGES X2.5, SUBJ. SB01
MR13-75, EXPR. OC41, CH.3, O1-PZ.
- VOLTAGE +
1 6 5 2 4
0 50 100 150 200 250 300
TIME IN MILLISECONDS
RED =
YELLOW =
GREEN =
BLUE =

50 EPOCH AVERAGES X2.5, SUBJ. SB01
MR13-75, EXPR. OC41, CH.4, O2-PZ.

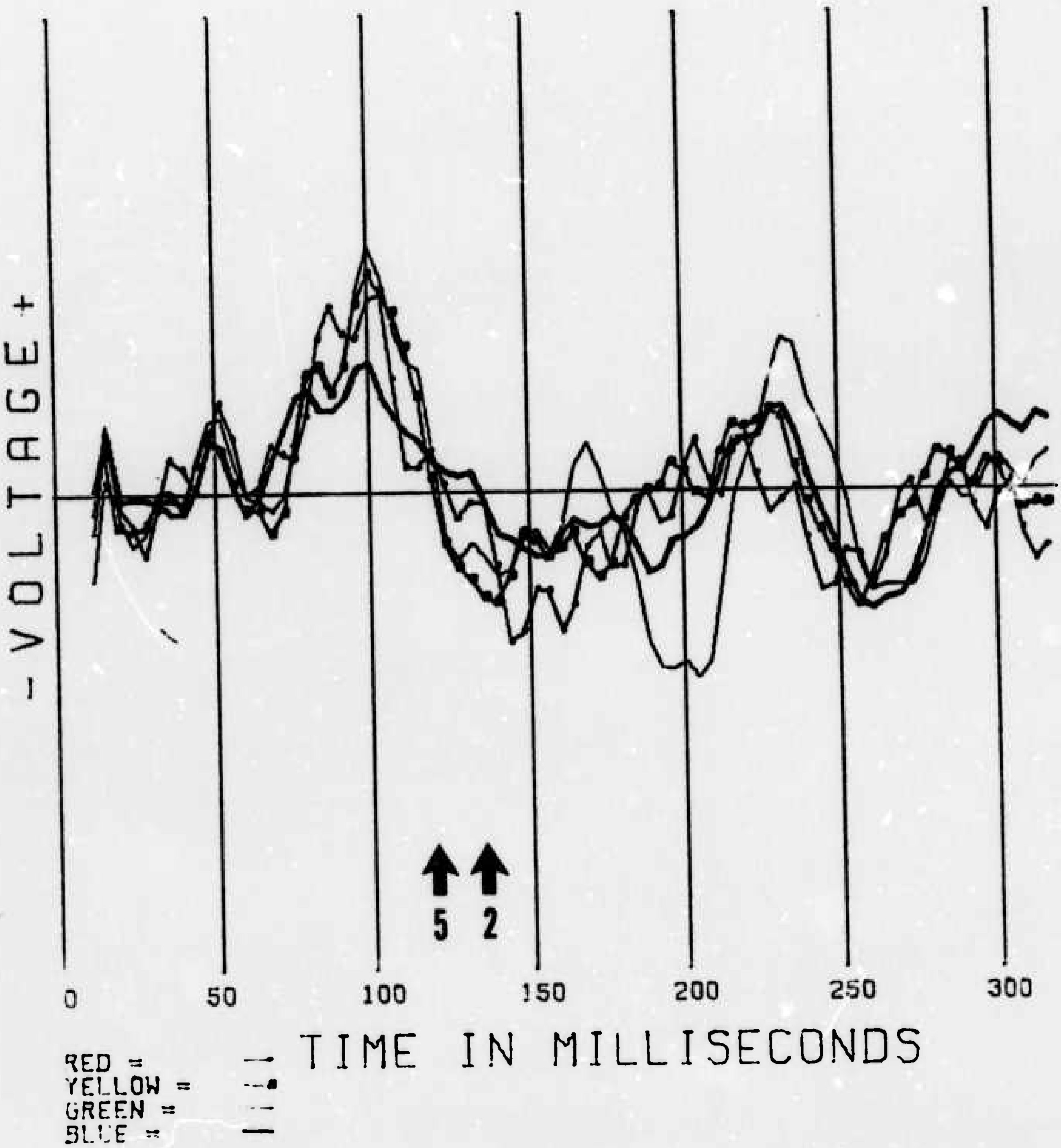


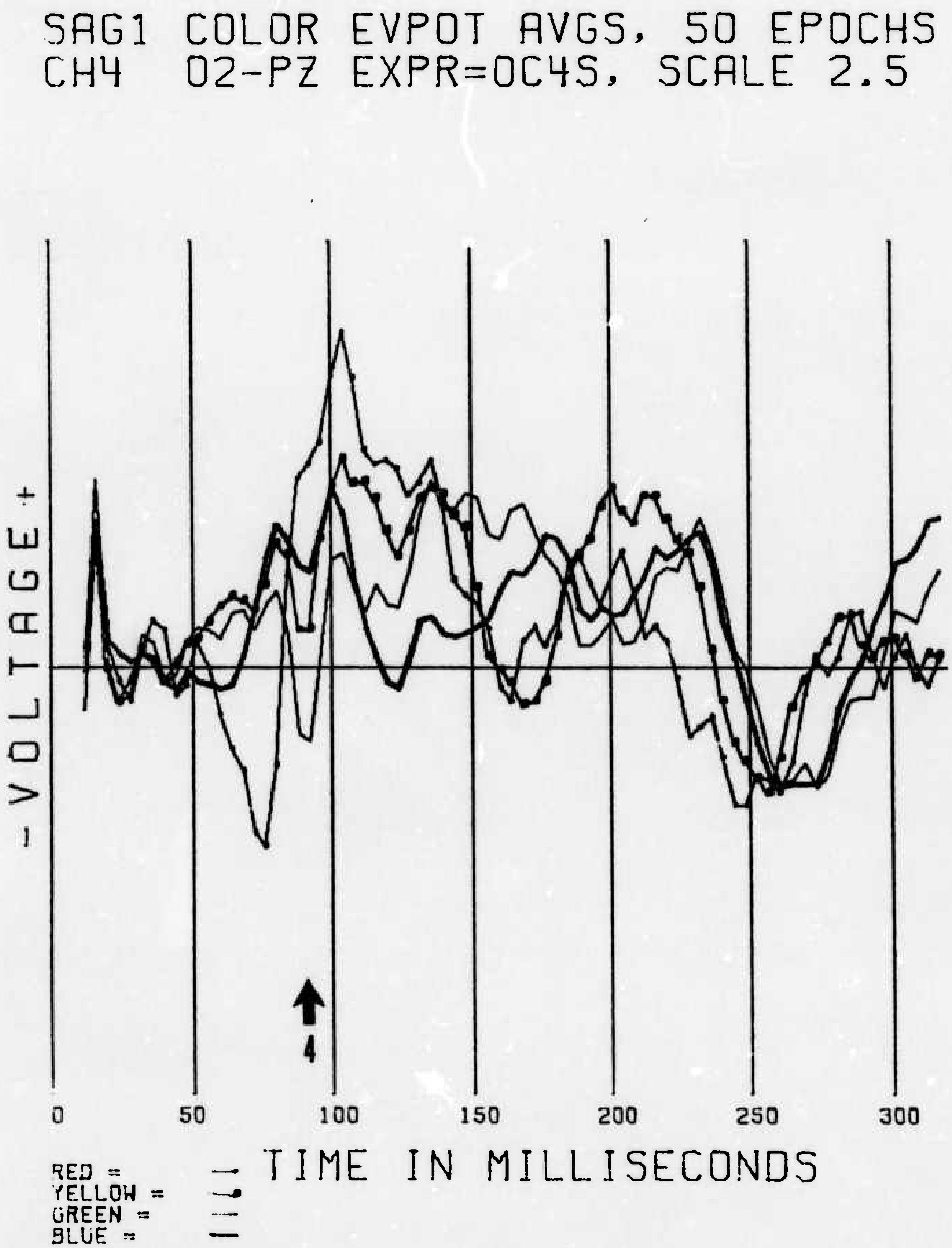
SAG1 COLOR EVPOT AVGS, 50 EPOCHS
CH 1 PZ-A, EXPR=OC4S, SCALE 2.5

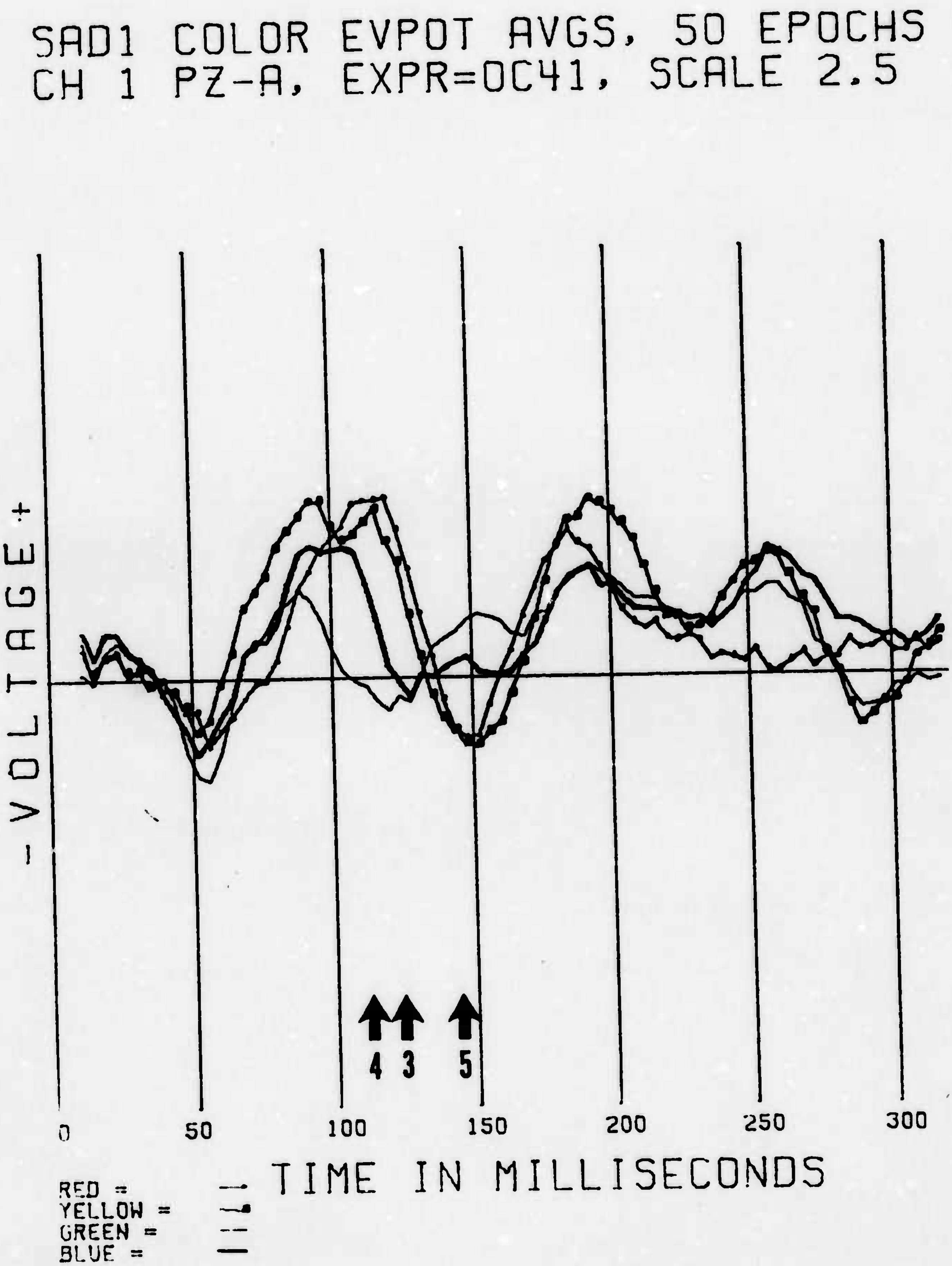


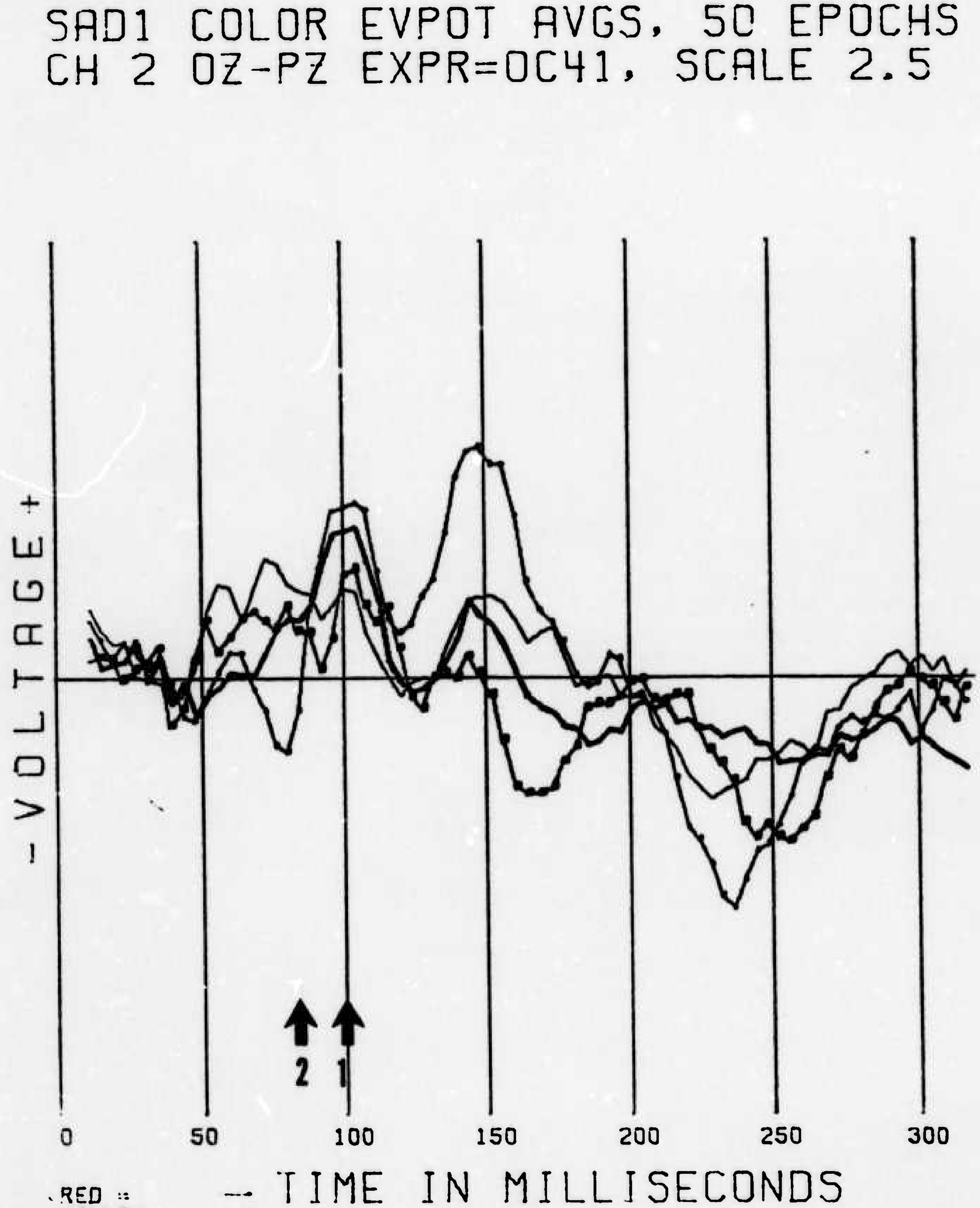

SAG1 COLOR EVPOT AVGS, 50 EPOCHS
CH 2 OZ-PZ EXPR=OC4S, SCALE 2.5
- VOLTAGE +
3
1
6
0
50
100
150
200
250
300
TIME IN MILLISECONDS
RED =
YELLOW =
GREEN =
BLUE =

SAG1 COLOR EVPOT AVGS, 50 EPOCHS
CH 3 01-PZ EXPR=OC4S, SCALE 2.5

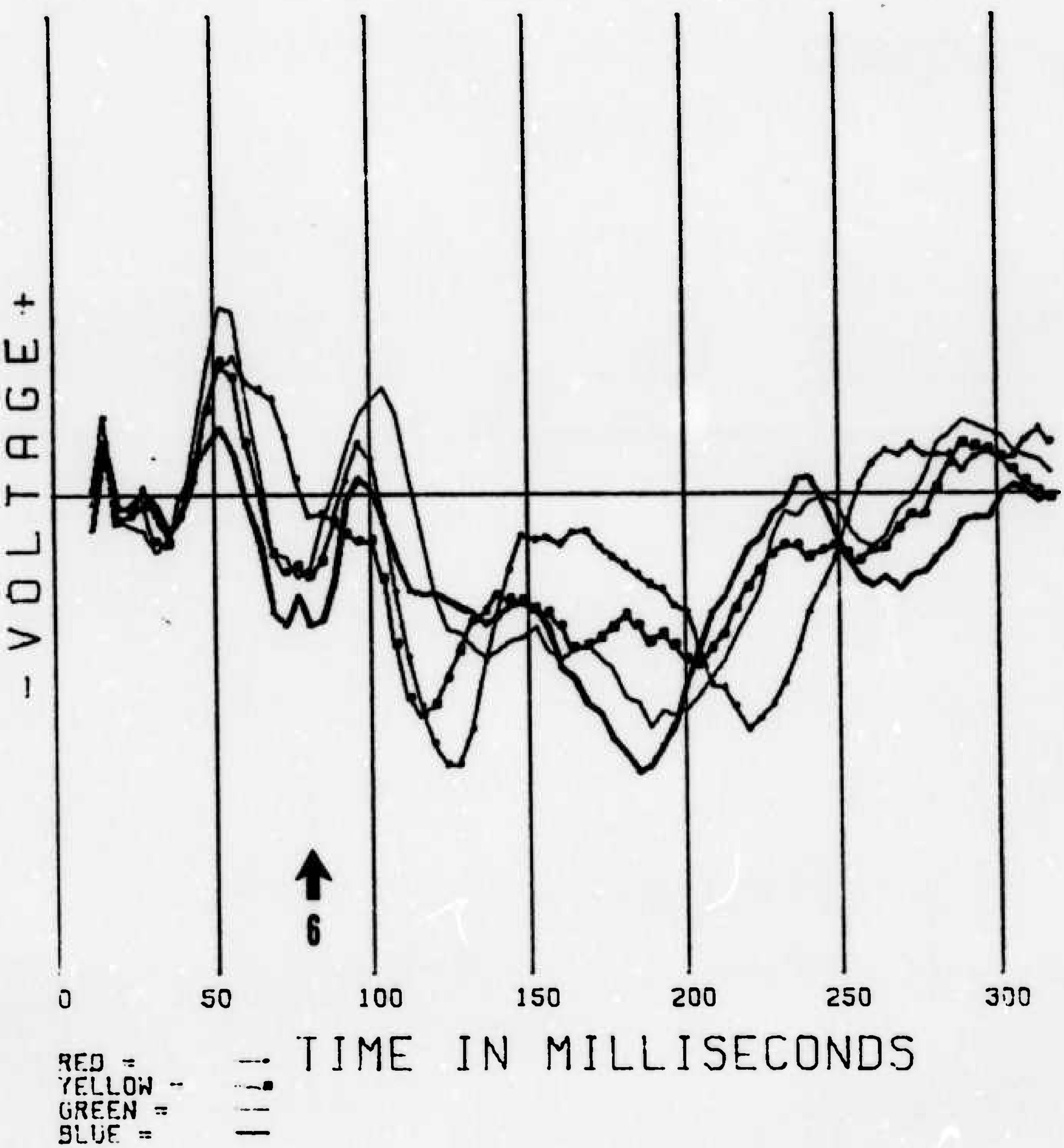



SAG1 COLOR EVPOT AVGS, 50 EPOCHS
CH4 O2-PZ EXPR=OC4S, SCALE 2.5
- VOLTAGE +
4
0
50
100
150
200
250
300
TIME IN MILLISECONDS
RED =
YELLOW =
GREEN =
BLUE =

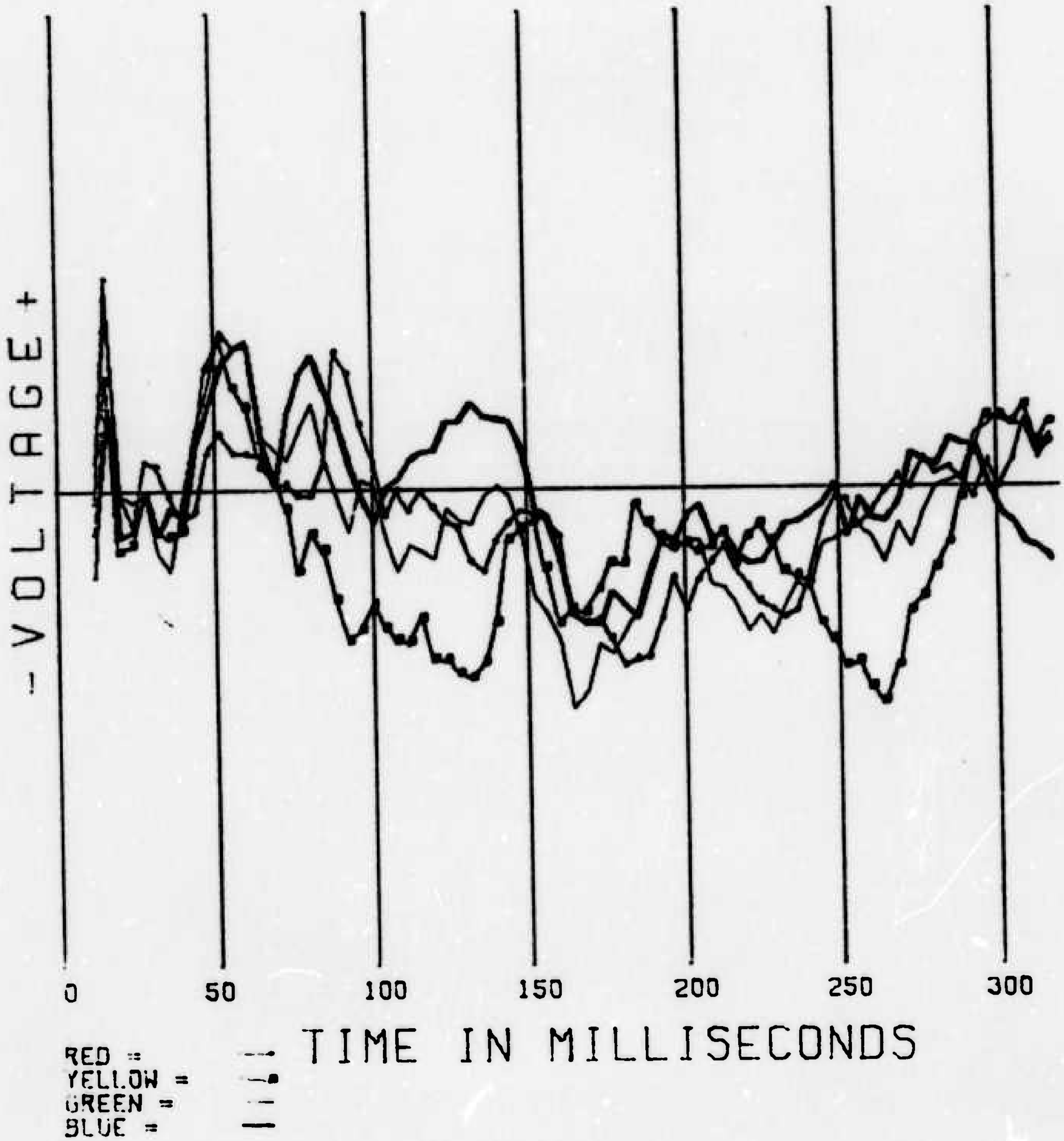

SAD1 COLOR EVPOT AVGS, 50 EPOCHS
CH 1 PZ-A, EXPR=OC41, SCALE 2.5
-VOLTAGE+
4
3
5
0
50
100
150
200
250
300
TIME IN MILLISECONDS
RED =
YELLOW =
GREEN =
BLUE =


SAD1 COLOR EVPOT AVGS, 50 EPOCHS
CH 2 OZ-PZ EXPR=OC41, SCALE 2.5
- VOLTAGE +
2
1
0
50
100
150
200
250
300
TIME IN MILLISECONDS
RED =
YELLOW =
GREEN =
BLUE =

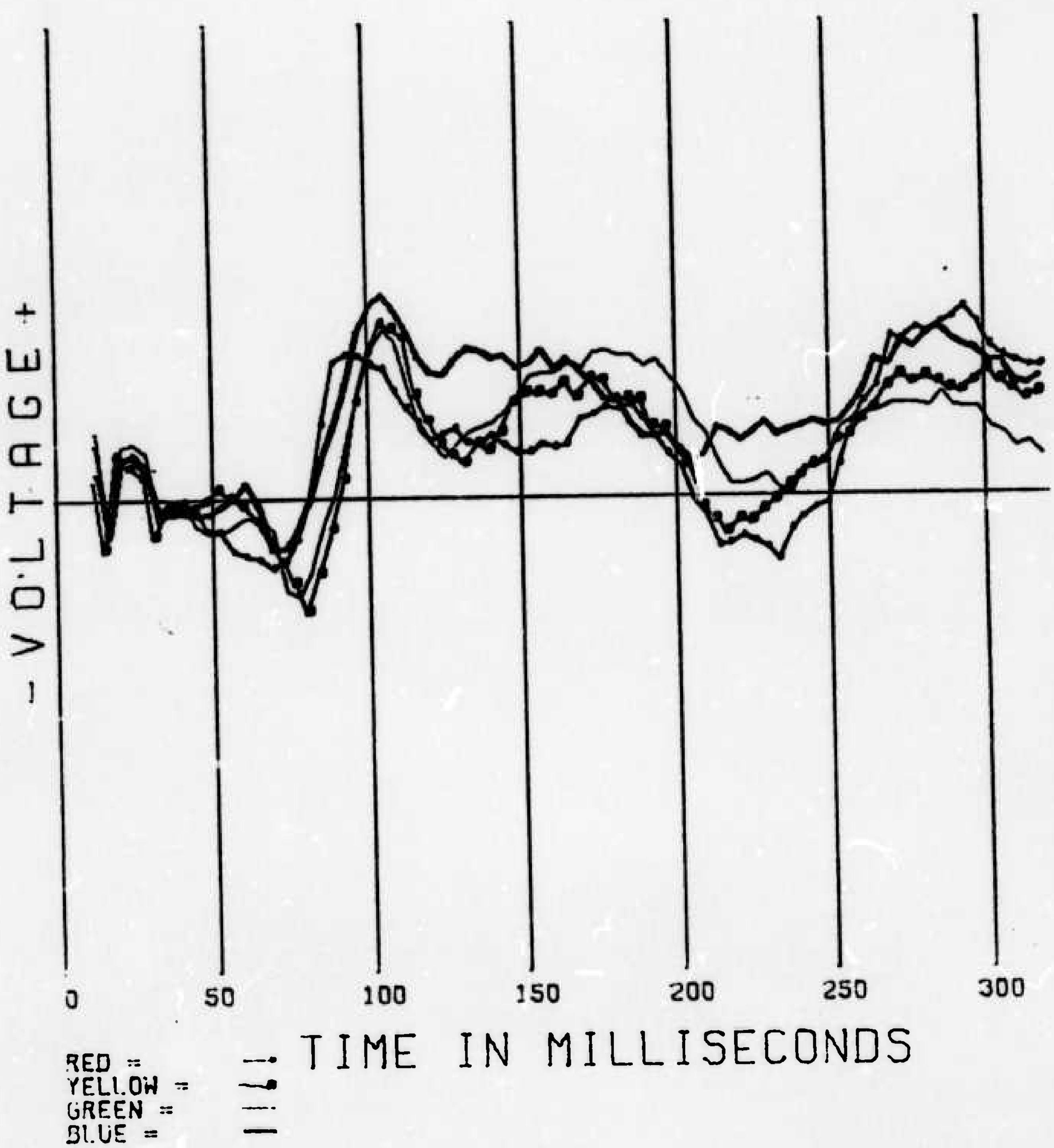
SAD1 COLOR EVPOT AVGS, 50 EPOCHS
CH 3 O1-PZ EXPR=OC41, SCALE 2.5



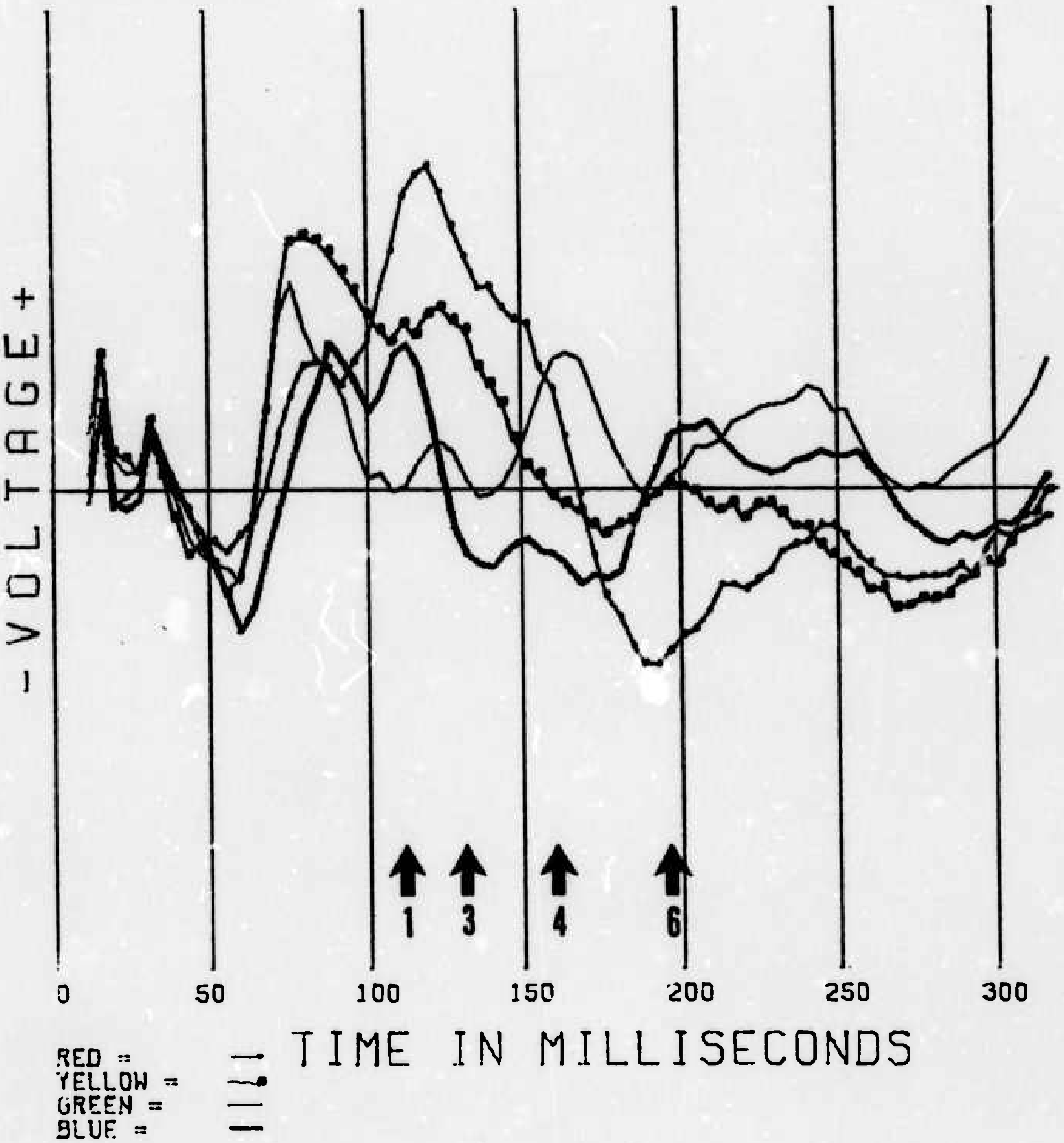
SAD1 COLOR EVPOT AVGS, 50 EPOCHS
CH 4 O2-PZ EXPR=OC41, SCALE 2.5



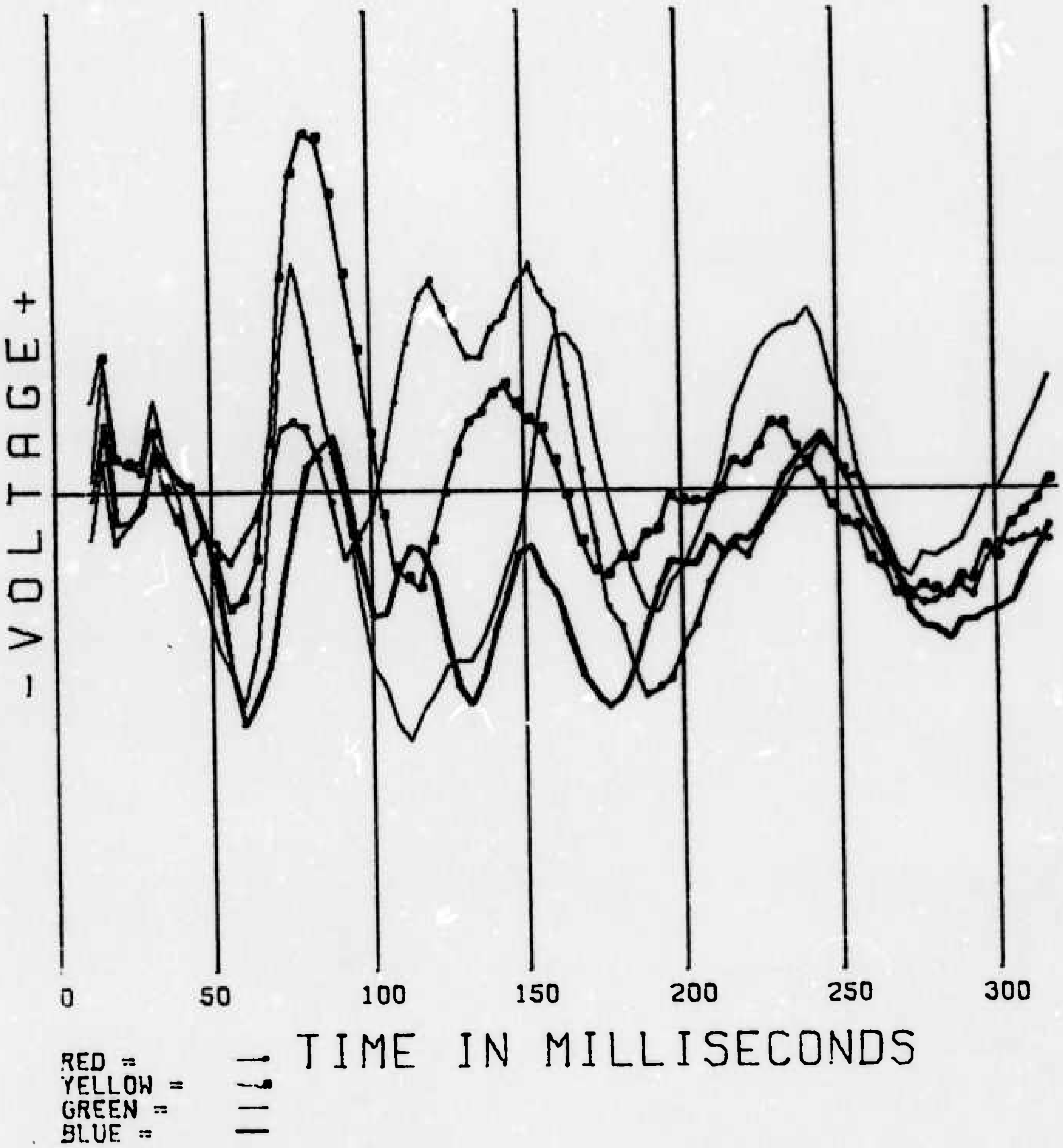
ATW1 COLOR EVPOT AVGS, 50 EPOCHS
CH 1 PZ-A, EXPR=OC41, SCALE 2.5



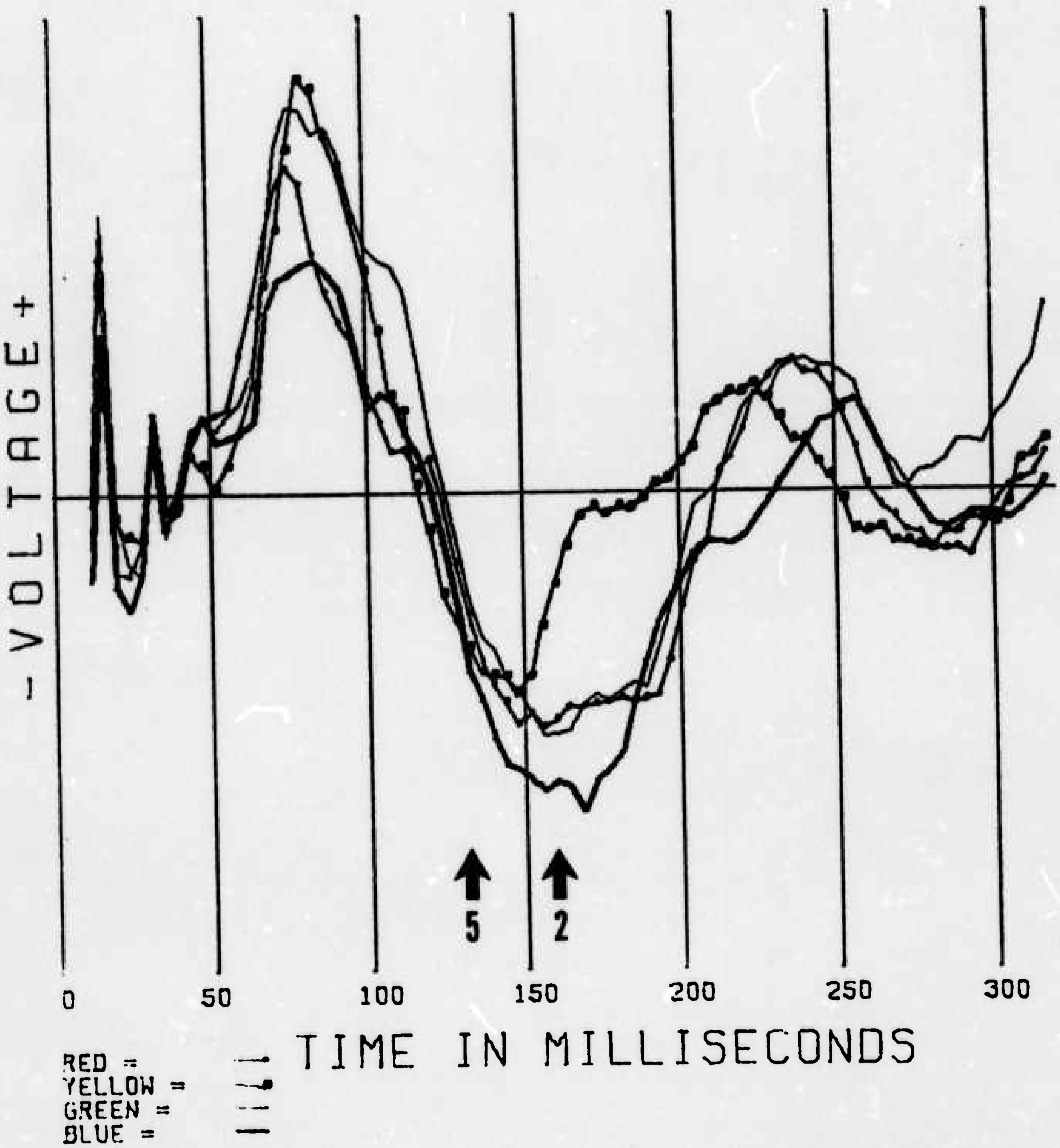
ATW1 COLOR EVPOT AVGS, 50 EPOCHS
CH 2 OZ-PZ EXPR=OC41, SCALE 2.5



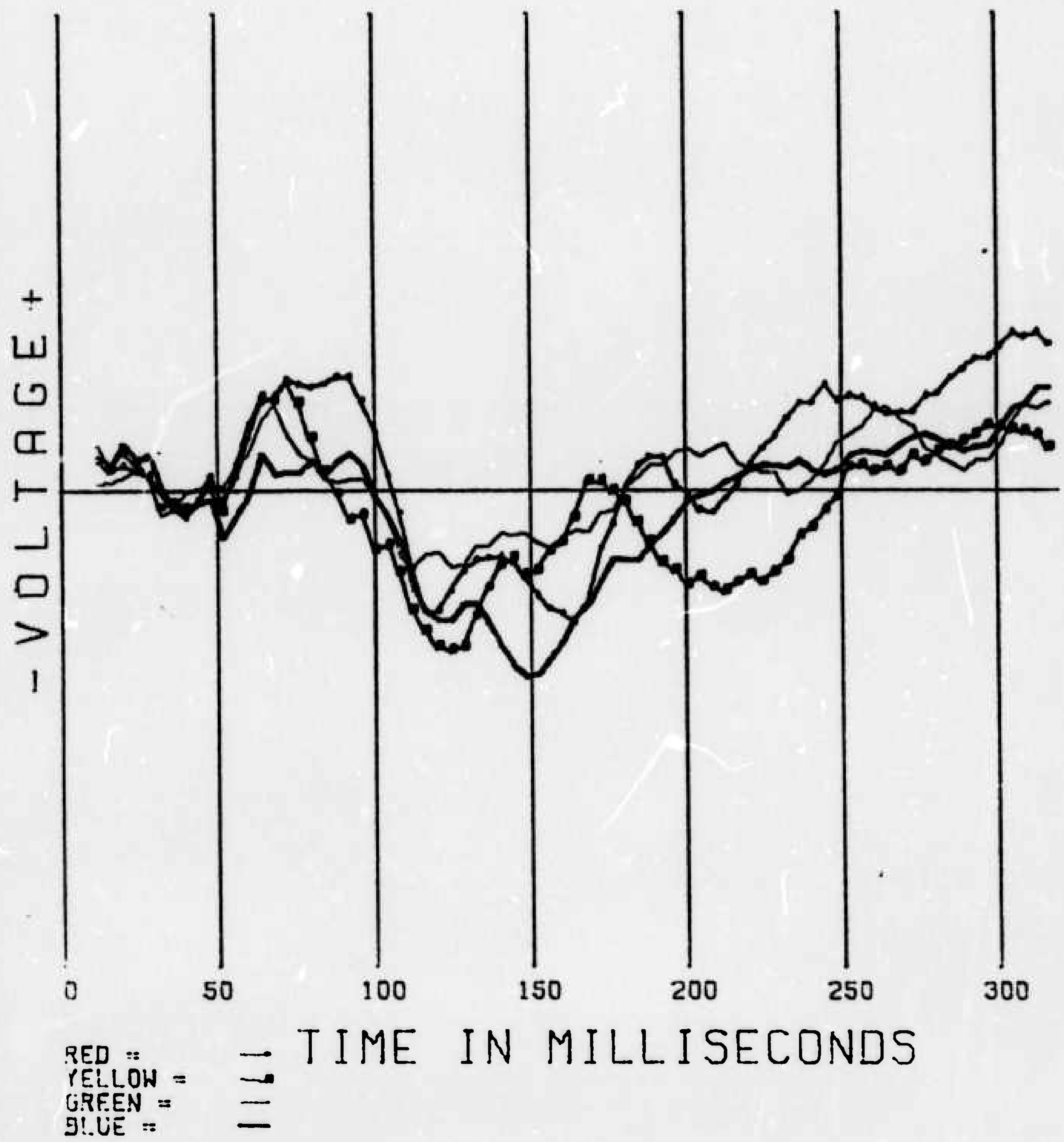
ATW1 COLOR EVPOT AVGS, 50 EPOCHS
CH 3 O1-PZ EXPR=OC41, SCALE 2.5



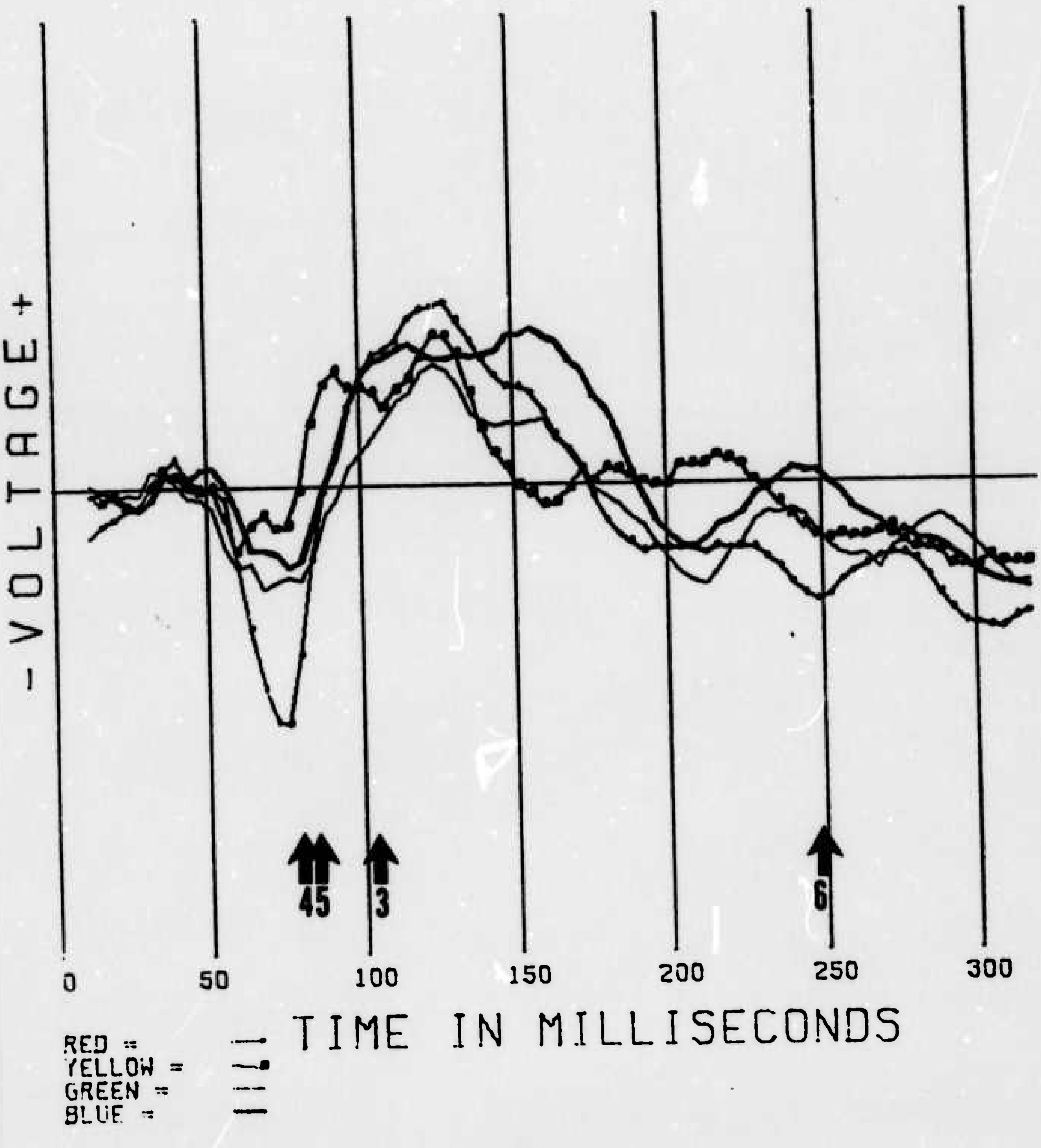
ATW1 COLOR EVPOT AVGS, 50 EPOCHS
CH 4 O2-PZ EXPR=OC41, SCALE 2.5



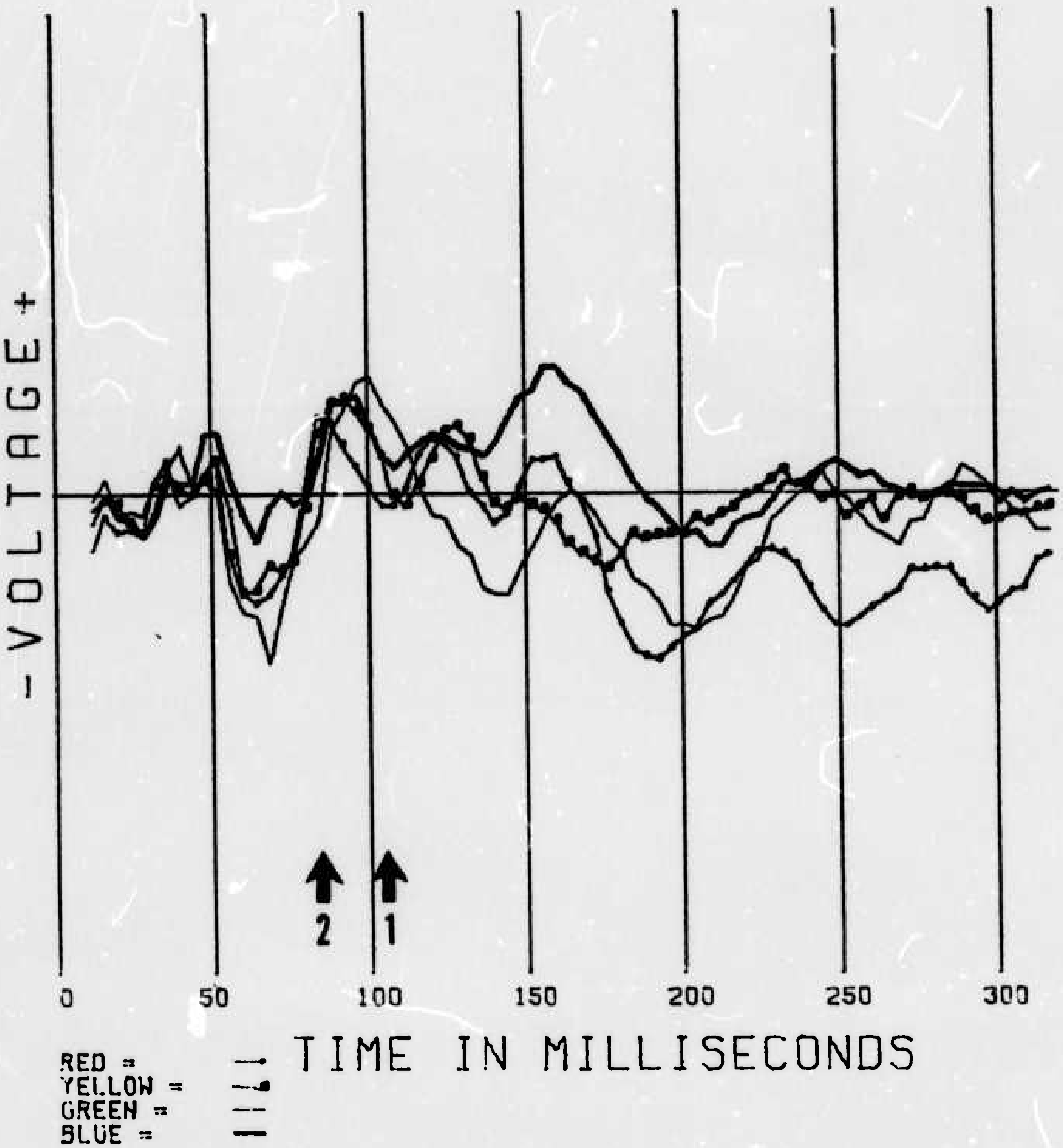
SOS1 COLOR EVPOT AVGS, 50 EPOCHS
CH 1 PZ-A, EXPR=OC41, SCALE 2.5



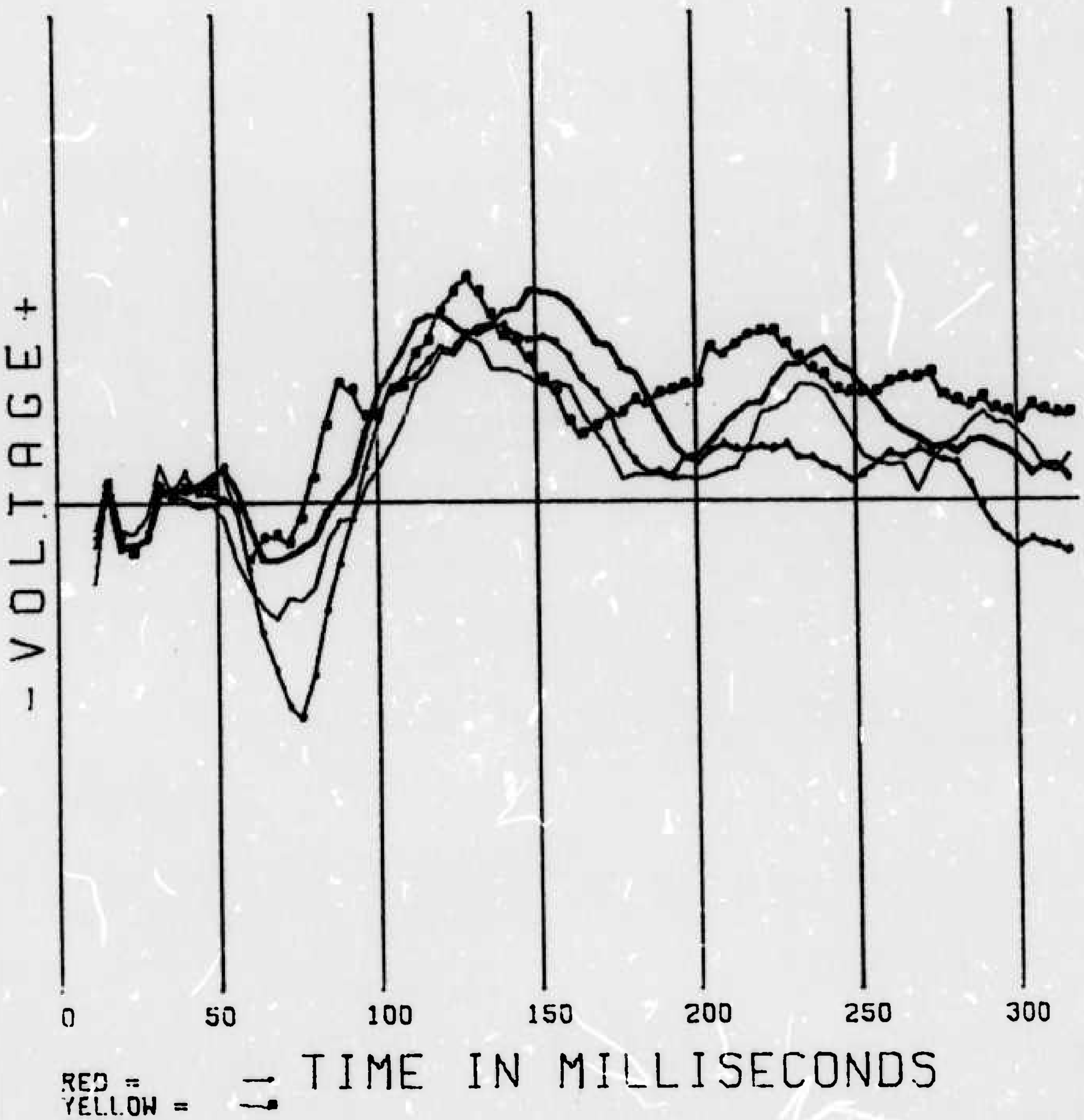
SOS1 COLOR EVPOT AVGS, 50 EPOCHS
CH 2 OZ-PZ EXPR=OC41, SCALE 2.5

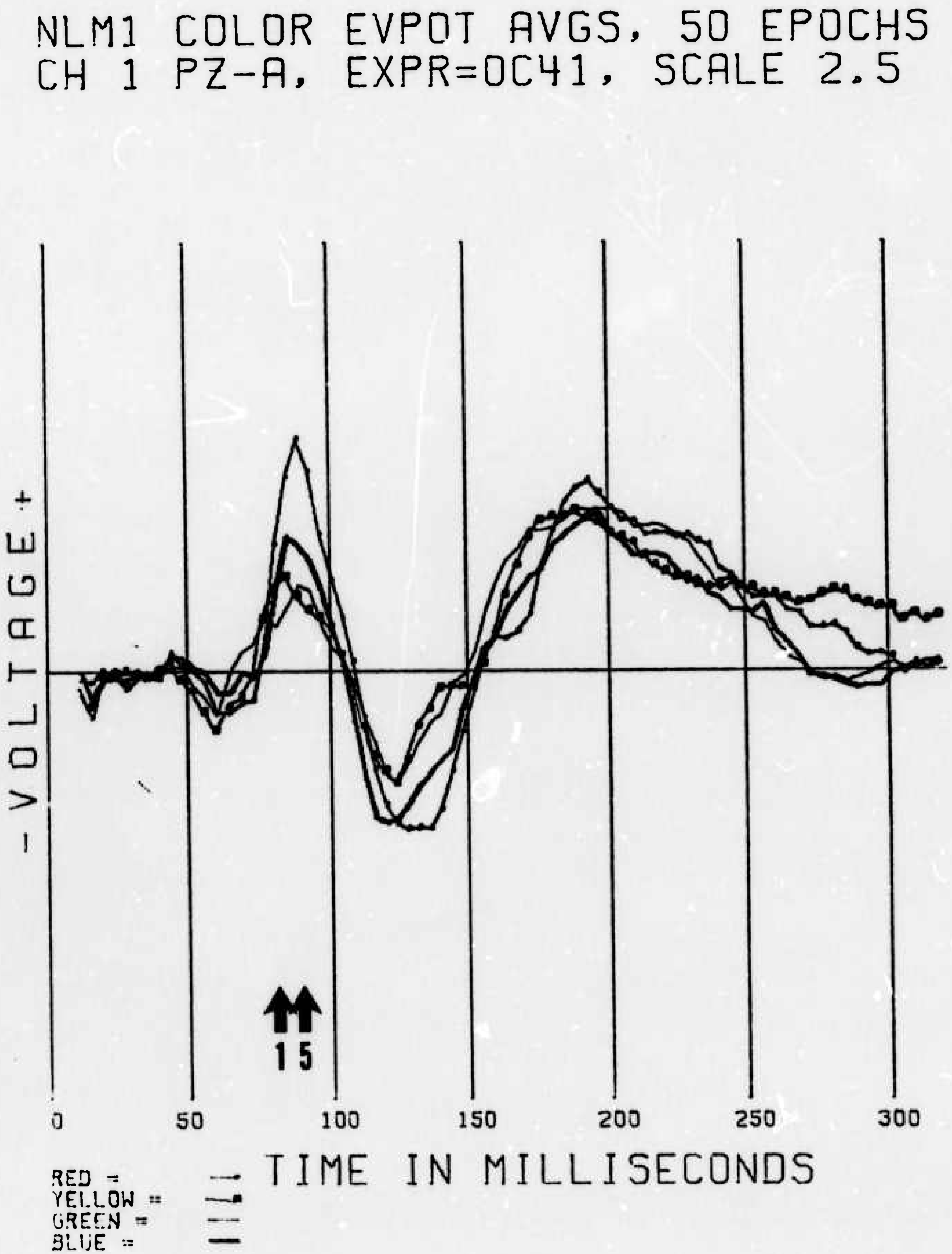


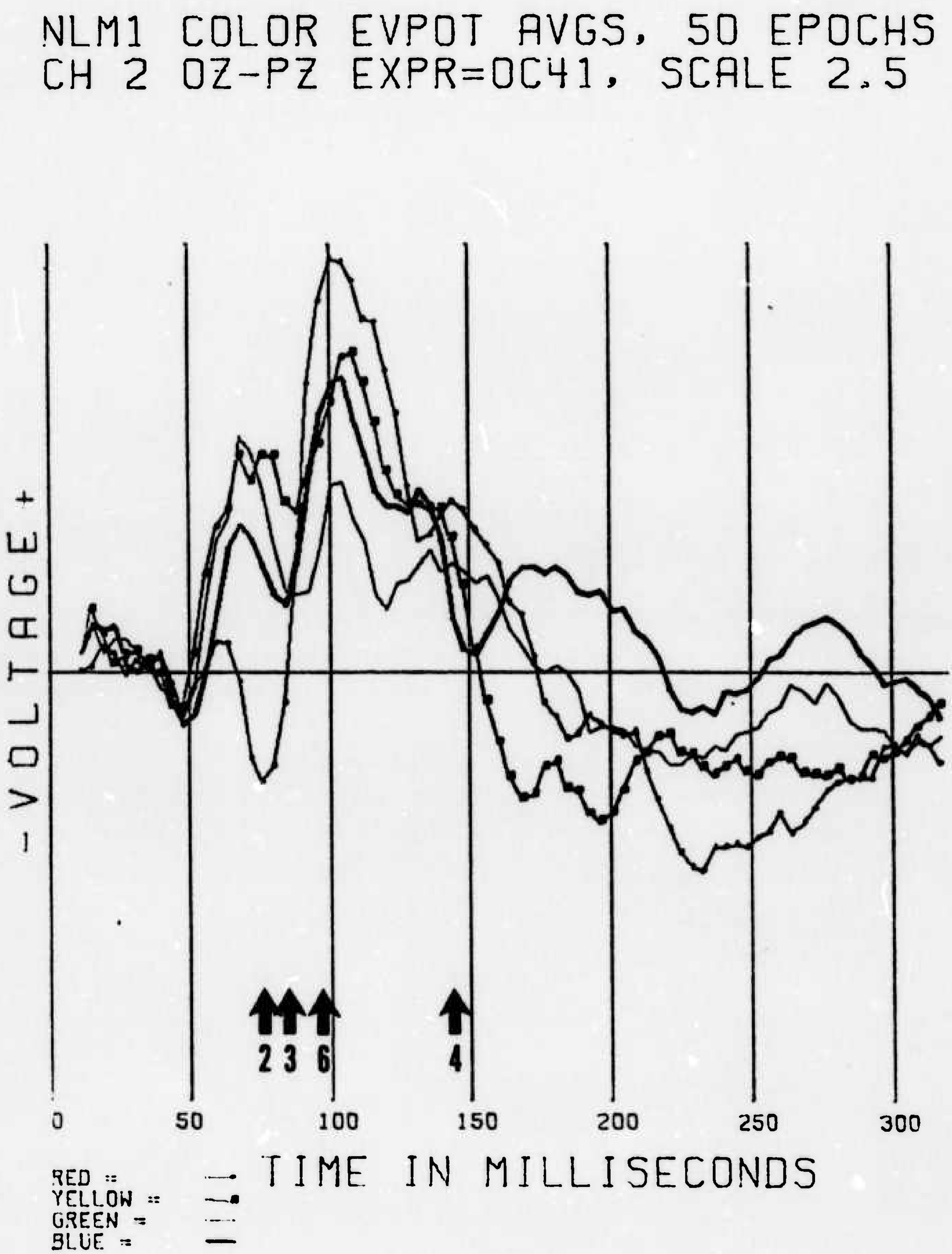
SOS1 COLOR EVPOT AVGS, 50 EPOCHS
CH 3 O1-PZ EXPR=OC41, SCALE 2.5



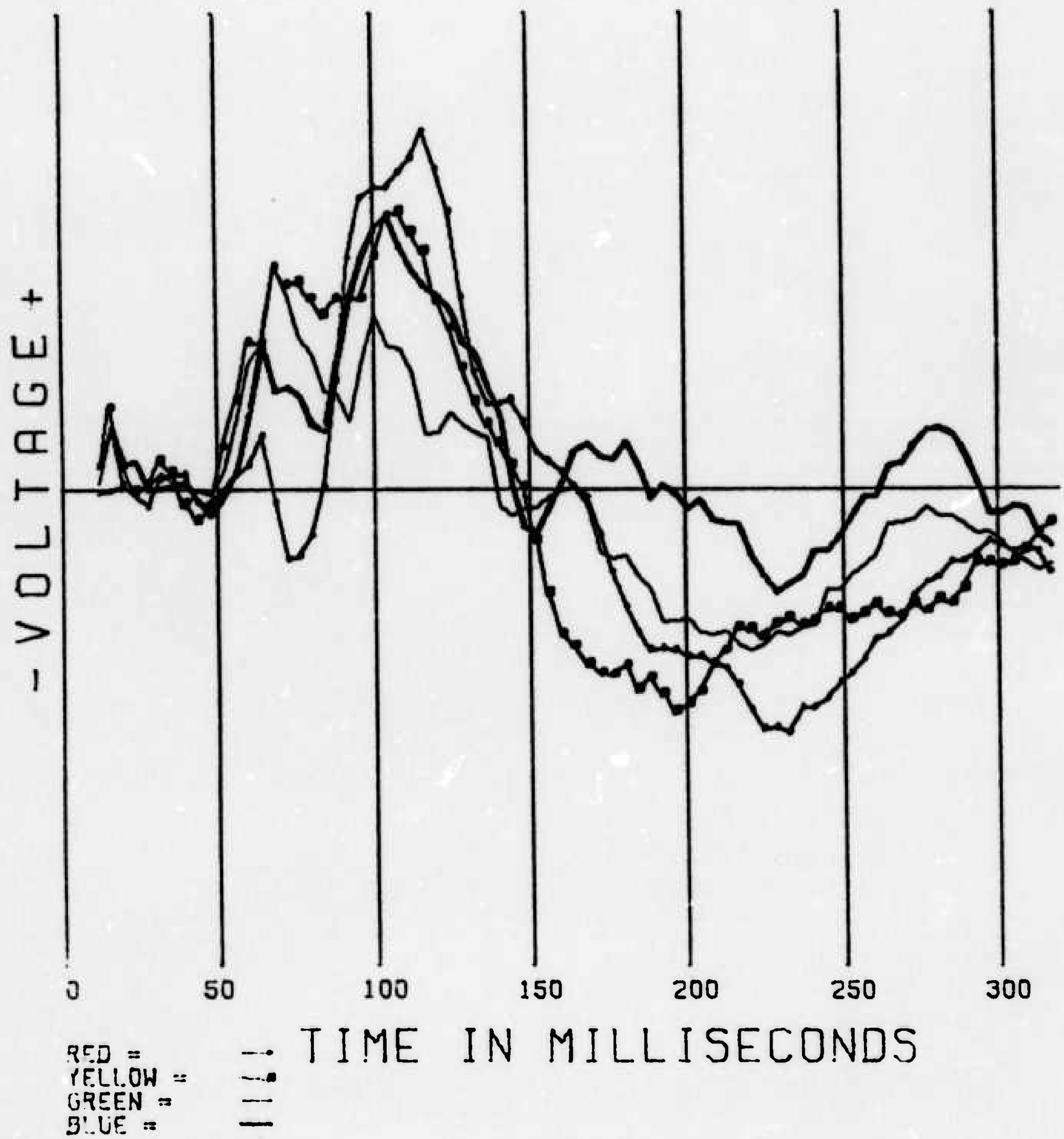
SOS1 COLOR EVPOT AVGS, 50 EPOCHS
CH 4 O2-PZ EXPR=OC41, SCALE 2.5



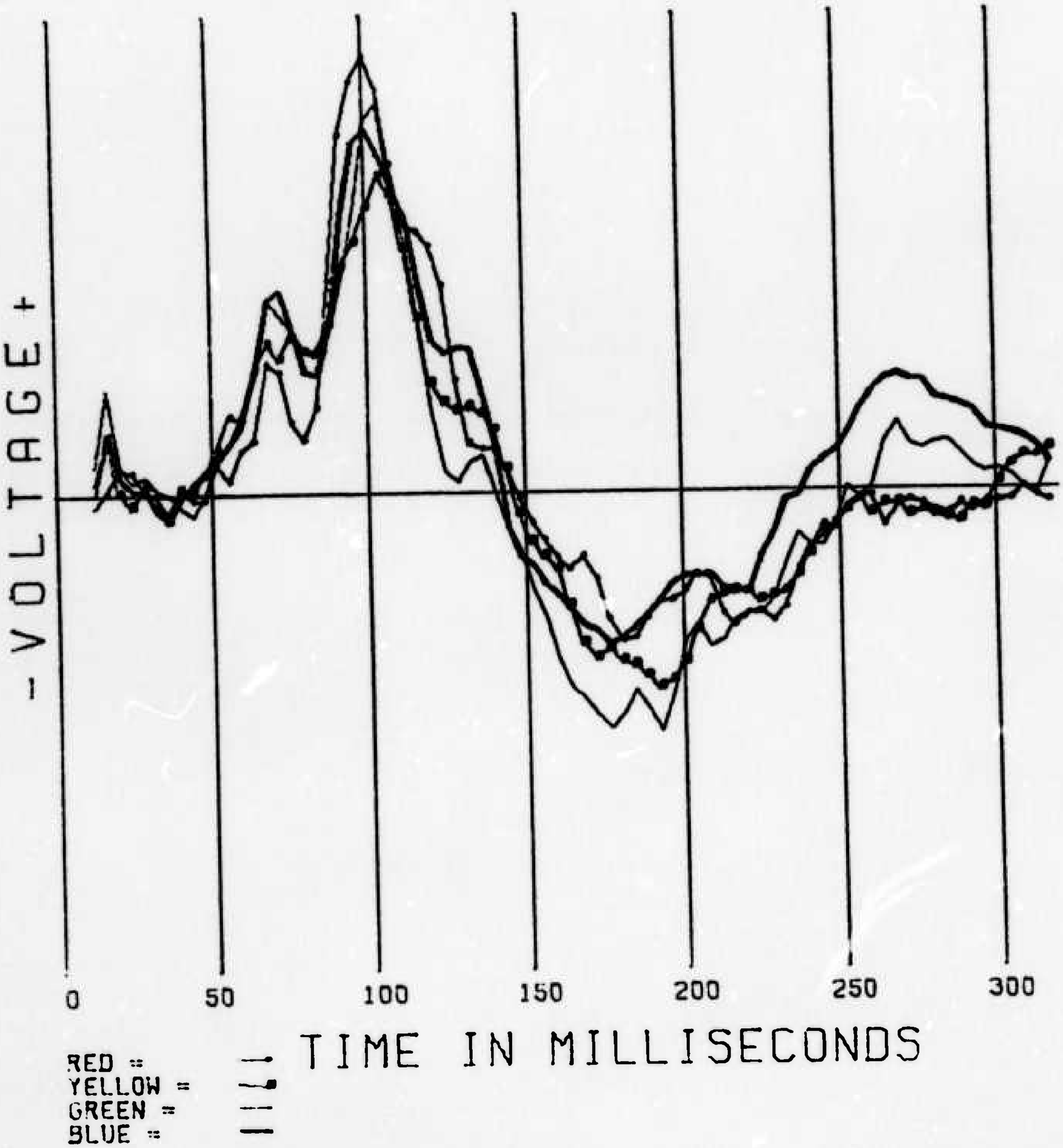

NLM1 COLOR EVPOT AVGS, 50 EPOCHS
CH 1 PZ-A, EXPR=OC41, SCALE 2.5
-VOLTAGE+
15
0
50
100
150
200
250
300
TIME IN MILLISECONDS
RED =
YELLOW =
GREEN =
BLUE =


NLM1 COLOR EVPOT AVGS, 50 EPOCHS
CH 2 OZ-PZ EXPR=OC41, SCALE 2.5
- VOLTAGE +
2 3 6
4
0
50
100
150
200
250
300
TIME IN MILLISECONDS
RED =
YELLOW =
GREEN =
BLUE =

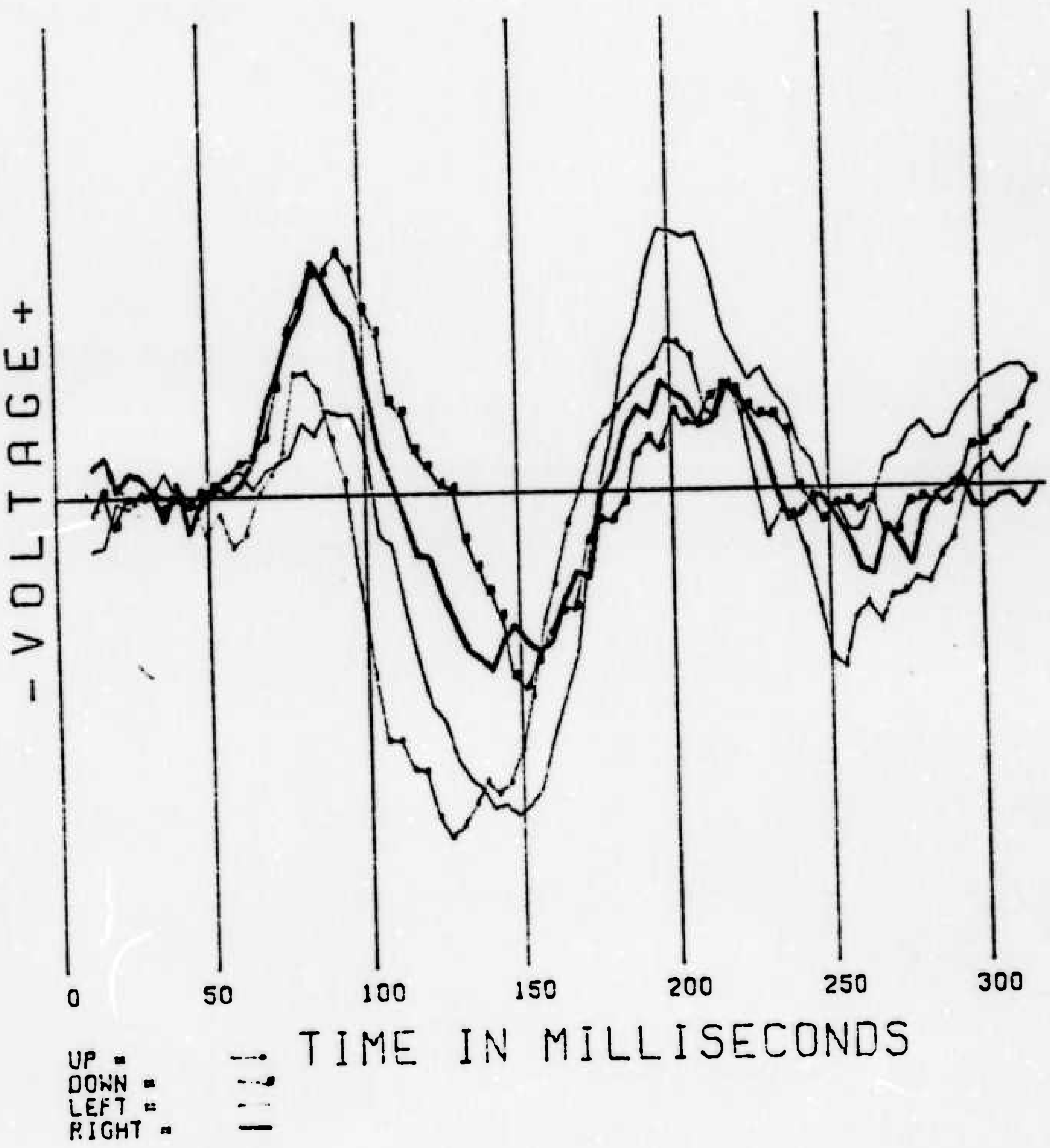
NLM1 COLOR EVPOT AVGS, 50 EPOCHS
CH 3 O1-PZ EXPR=OC41, SCALE 2.5



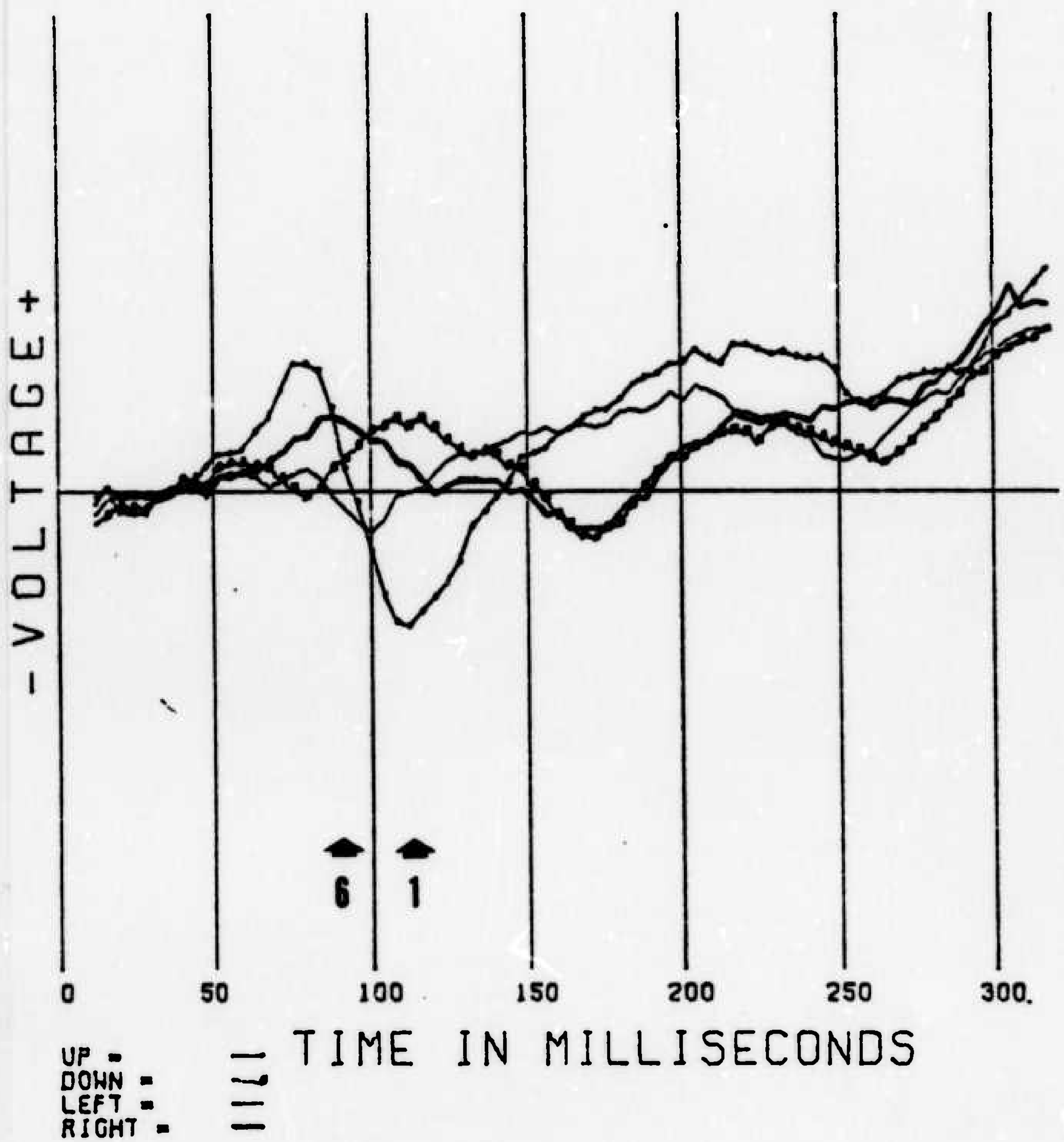
NLM1 COLOR EVPOT AVGS, 50 EPOCHS
CH 4 O2-PZ EXPR=OC41, SCALE 2.5



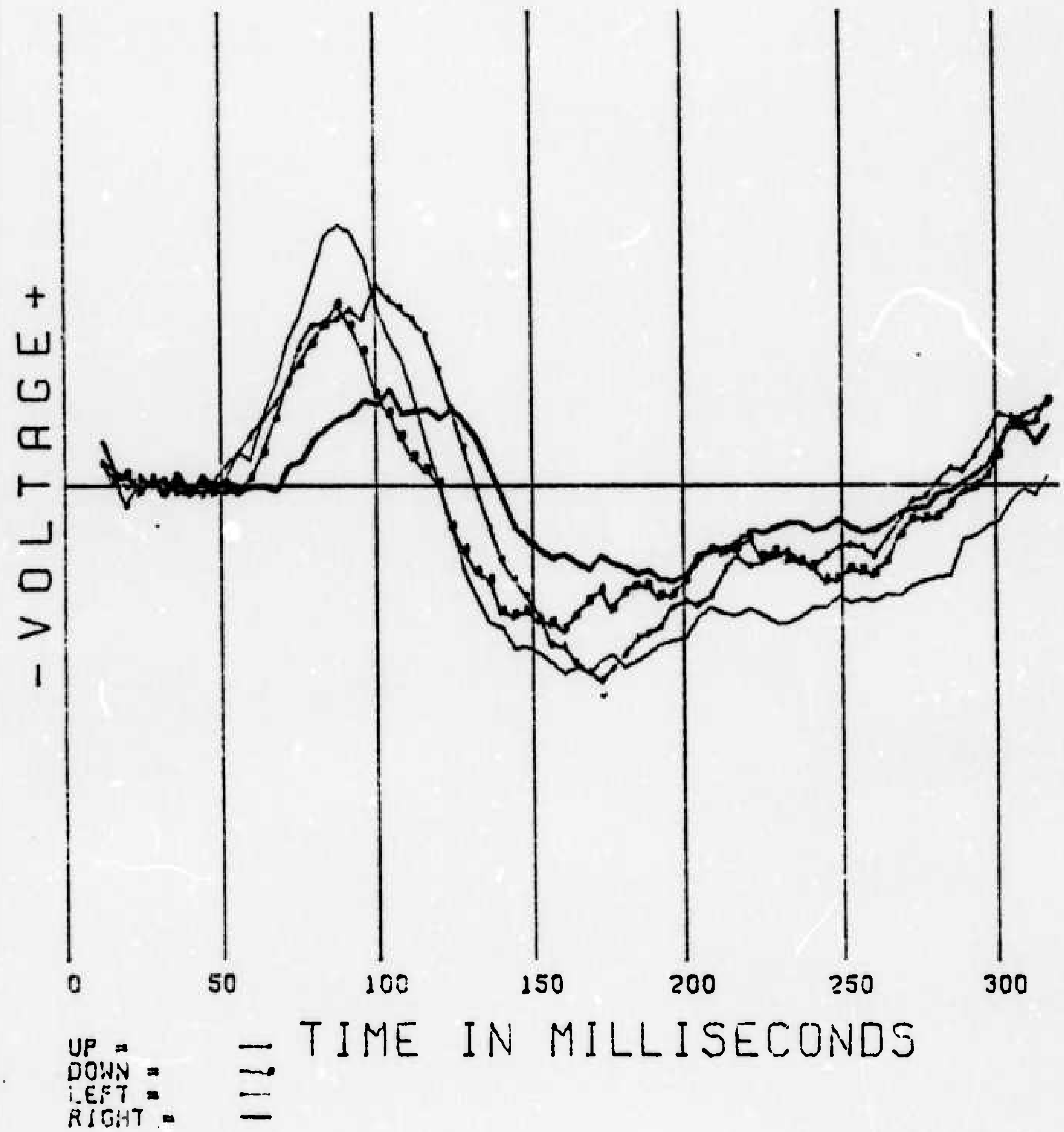
SOS2-MY28-75 ONLINE CONTROL CH1 OZ-A
50 EPOCH AVERAGE X 2.5, EXPR=CB41



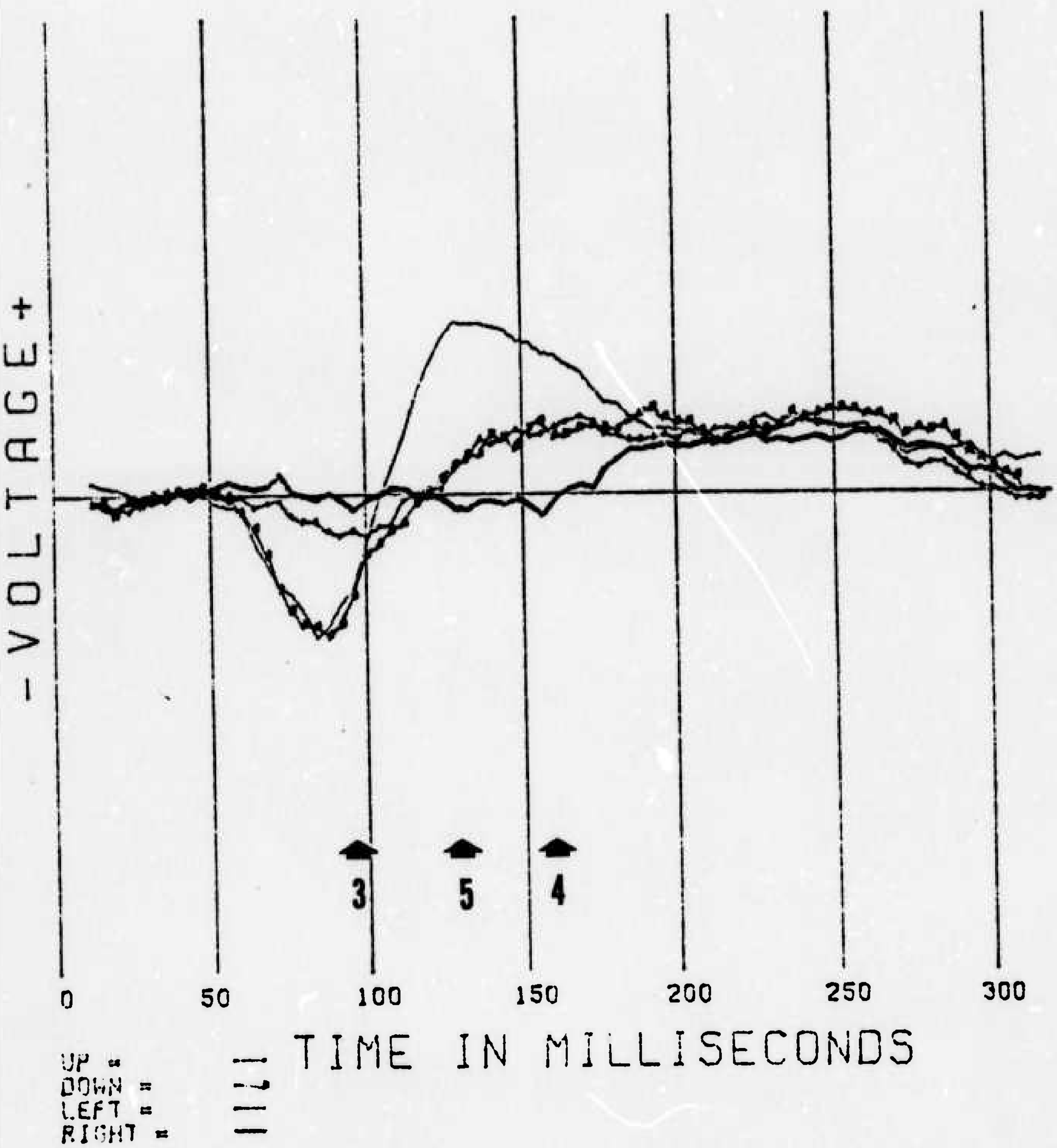
SOS2-MY28-75 ONLINE CONTROL CH2 PZ-OZ
50 EPOCH AVERAGE X 2.5, EXPR=CB41



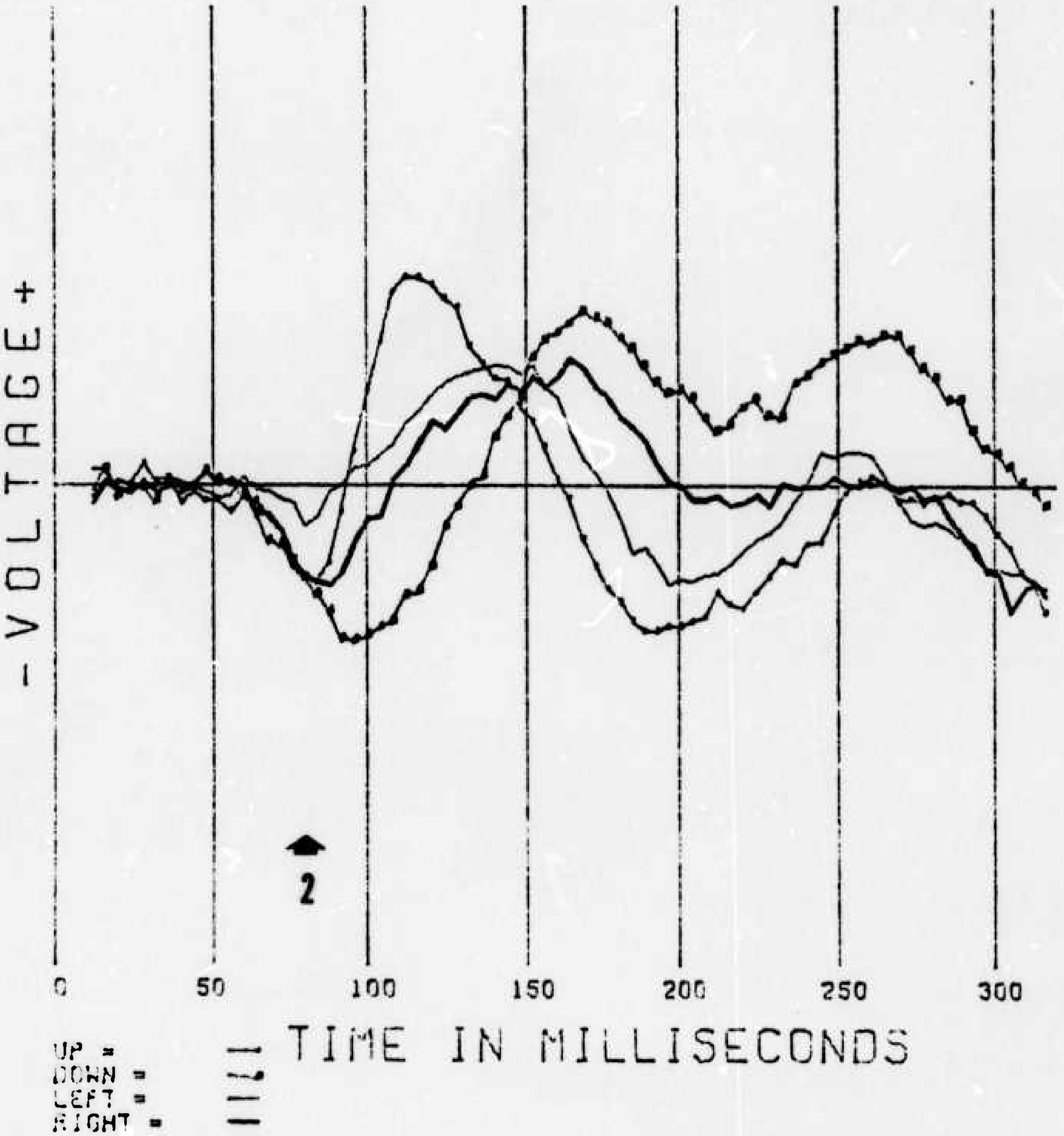
SOS2-MY28-75 ONLINE CONTROL CH3 01-0Z
50 EPOCH AVERAGE X 2.5, EXPR=CB41



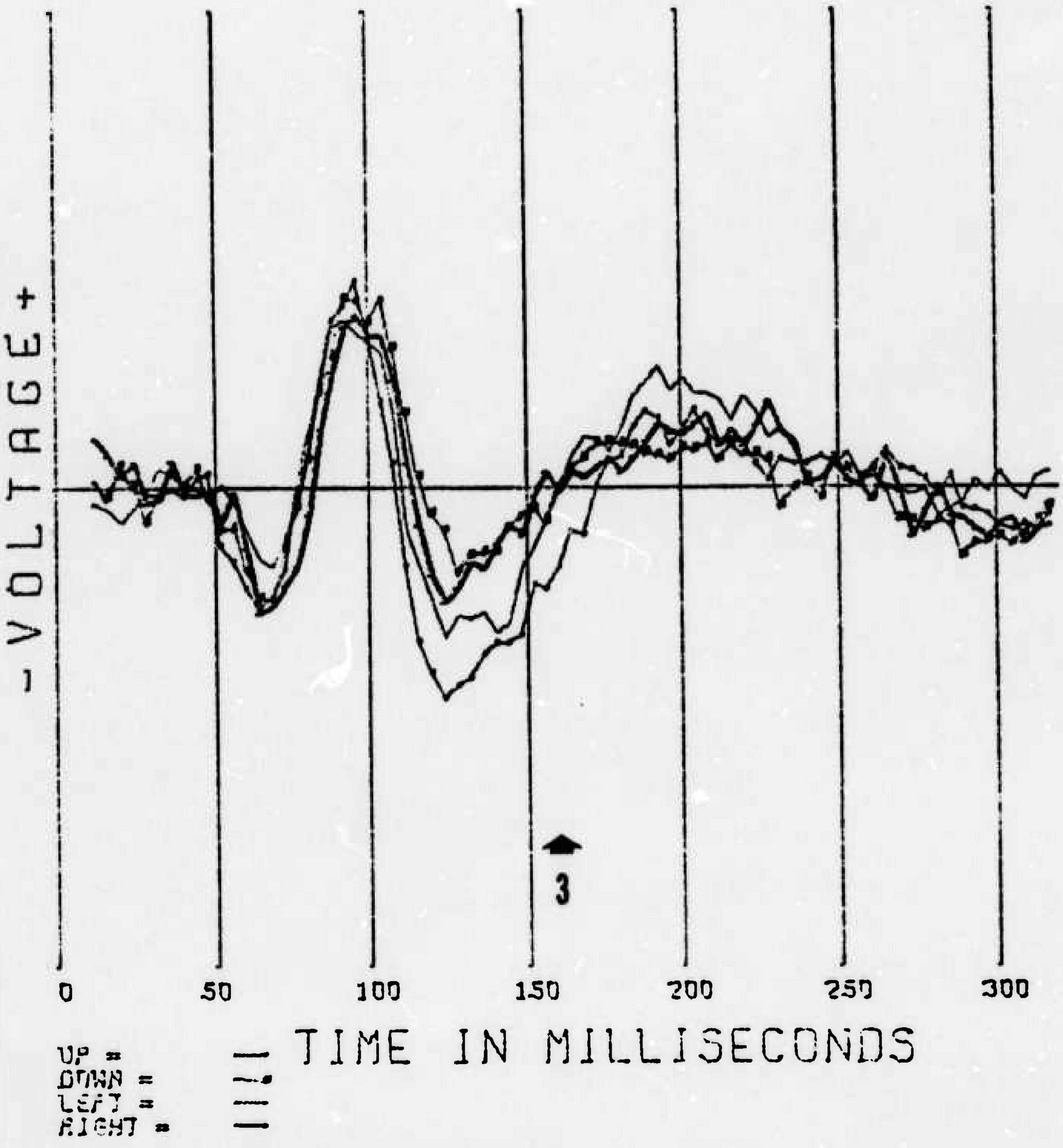
SOS2-MY28-75 ONLINE CONTROL CH4 O2-OZ
50 EPOCH AVERAGE X 2.5, EXPR=CB41



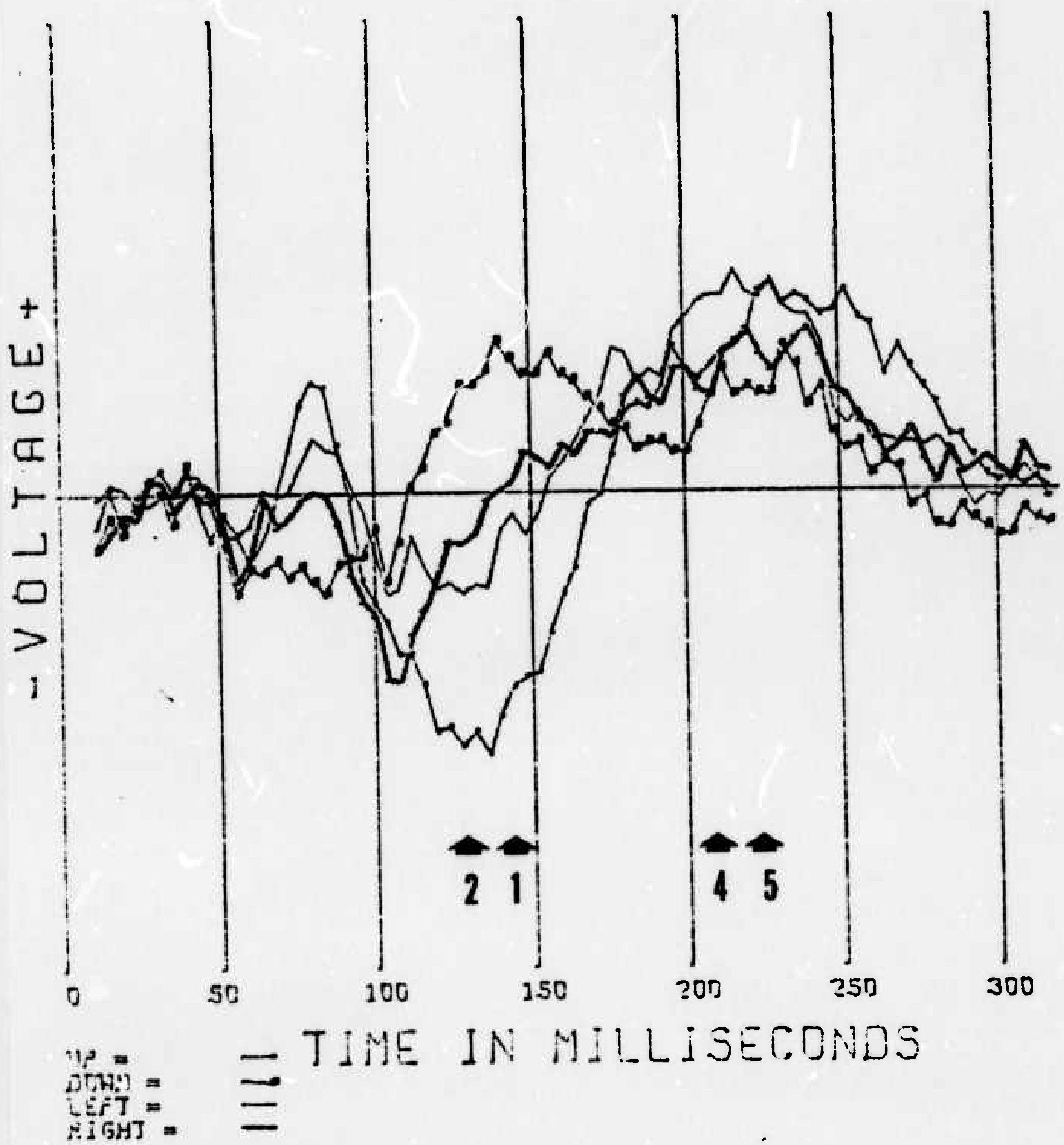
SOS2-MY28-75 ONLINE CONTROL CH5 I-OZ
50 EPOCH AVERAGE X 2.5, EXPR=CB41



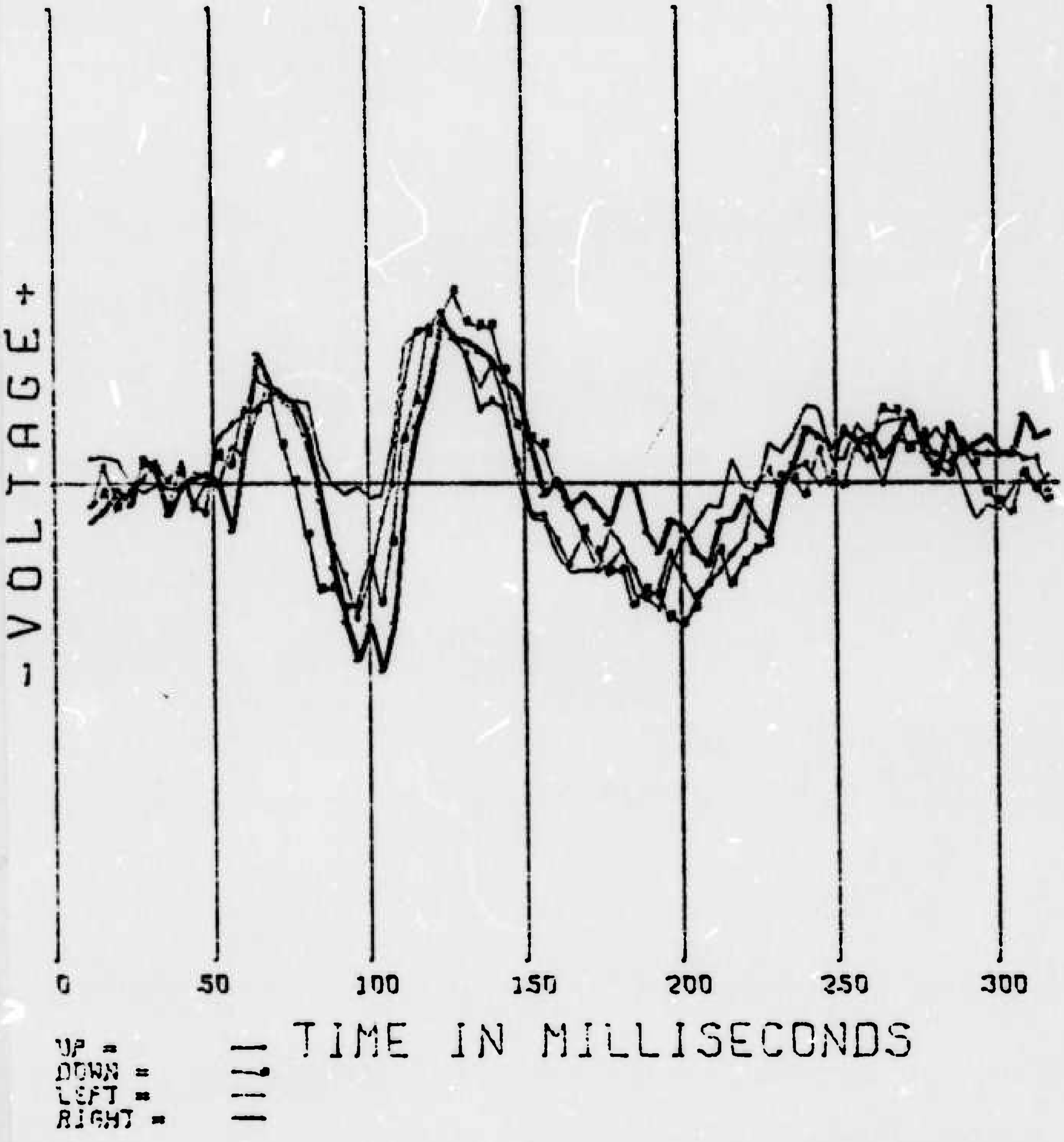
SAG2-MY30-75 ONLINE CONTROL CH1 OZ-A
50 EPOCH AVERAGE X 2.5, EXPR=CB41



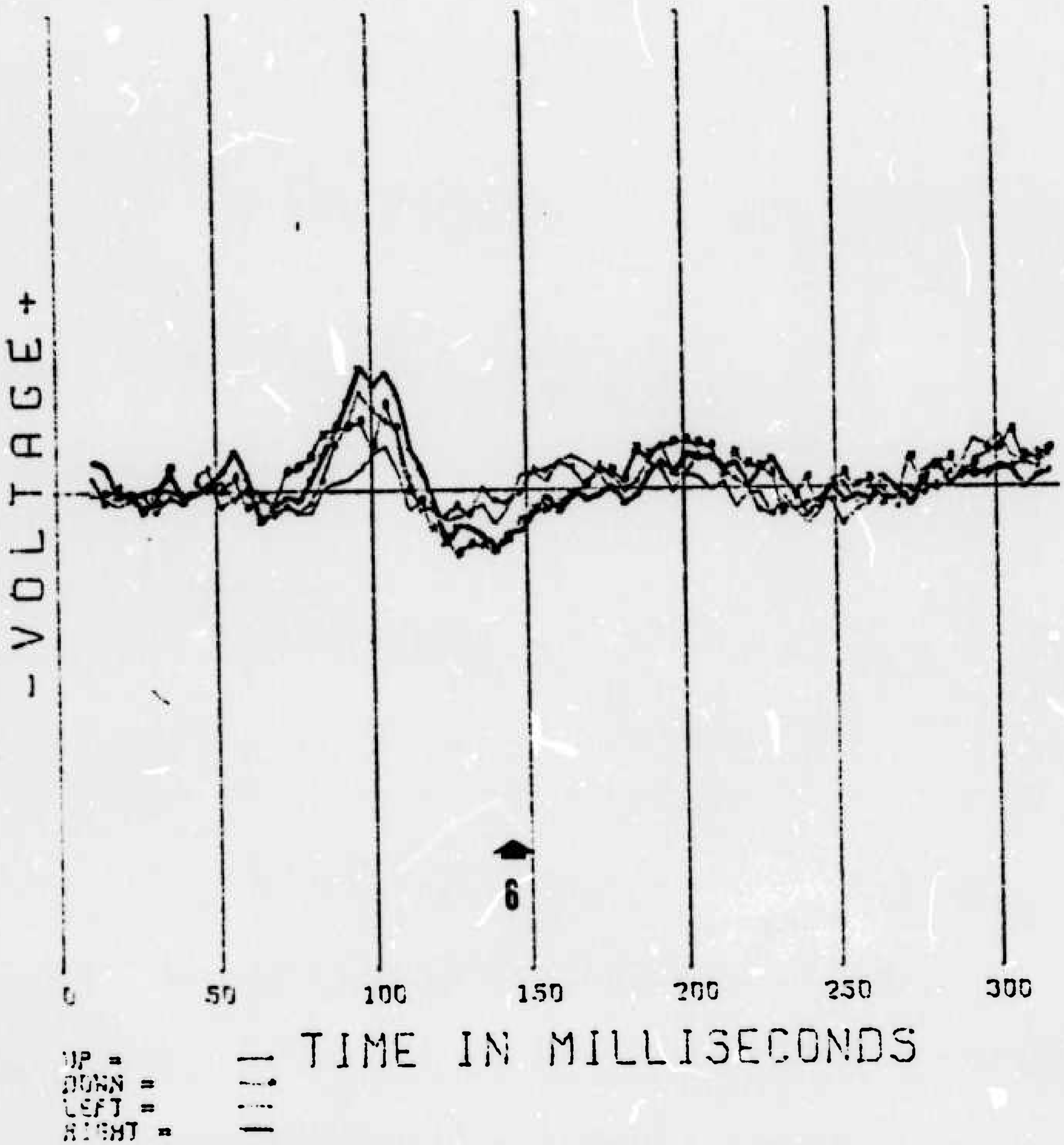
SAG2-MY30-75 ONLINE CONTROL CH2 PZ-OZ
50 EPOCH AVERAGE X 2.5, EXPR=CB41



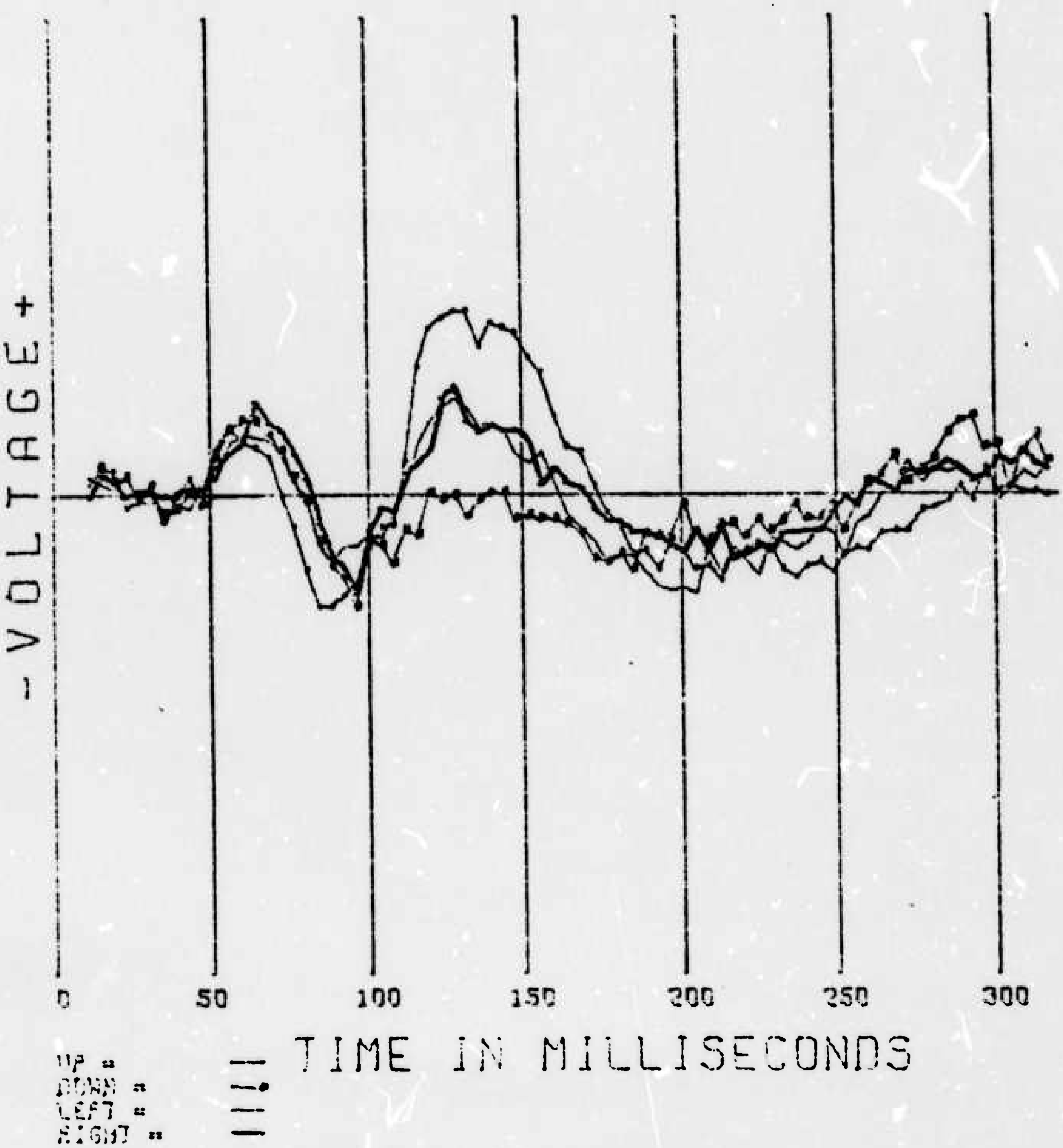
SAG2-MY30-75 ONLINE CONTROL CH3 01-07
50 EPOCH AVERAGE X 2.5, EXPR=CB41



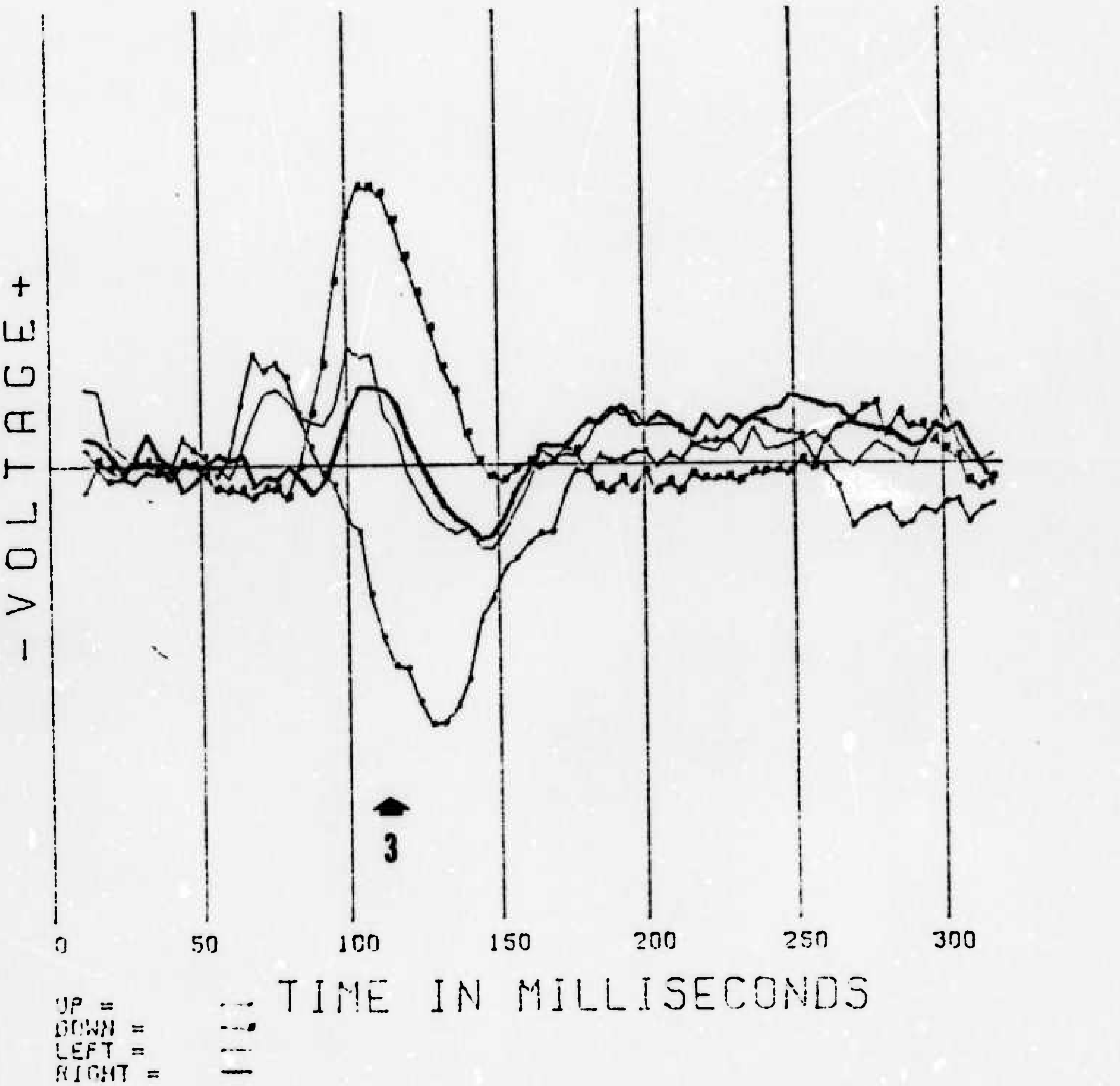
SAG2-MY30-75 ONLINE CONTROL CH4 02-03
50 EPOCH AVERAGE X 2.5, EXPR=CB41



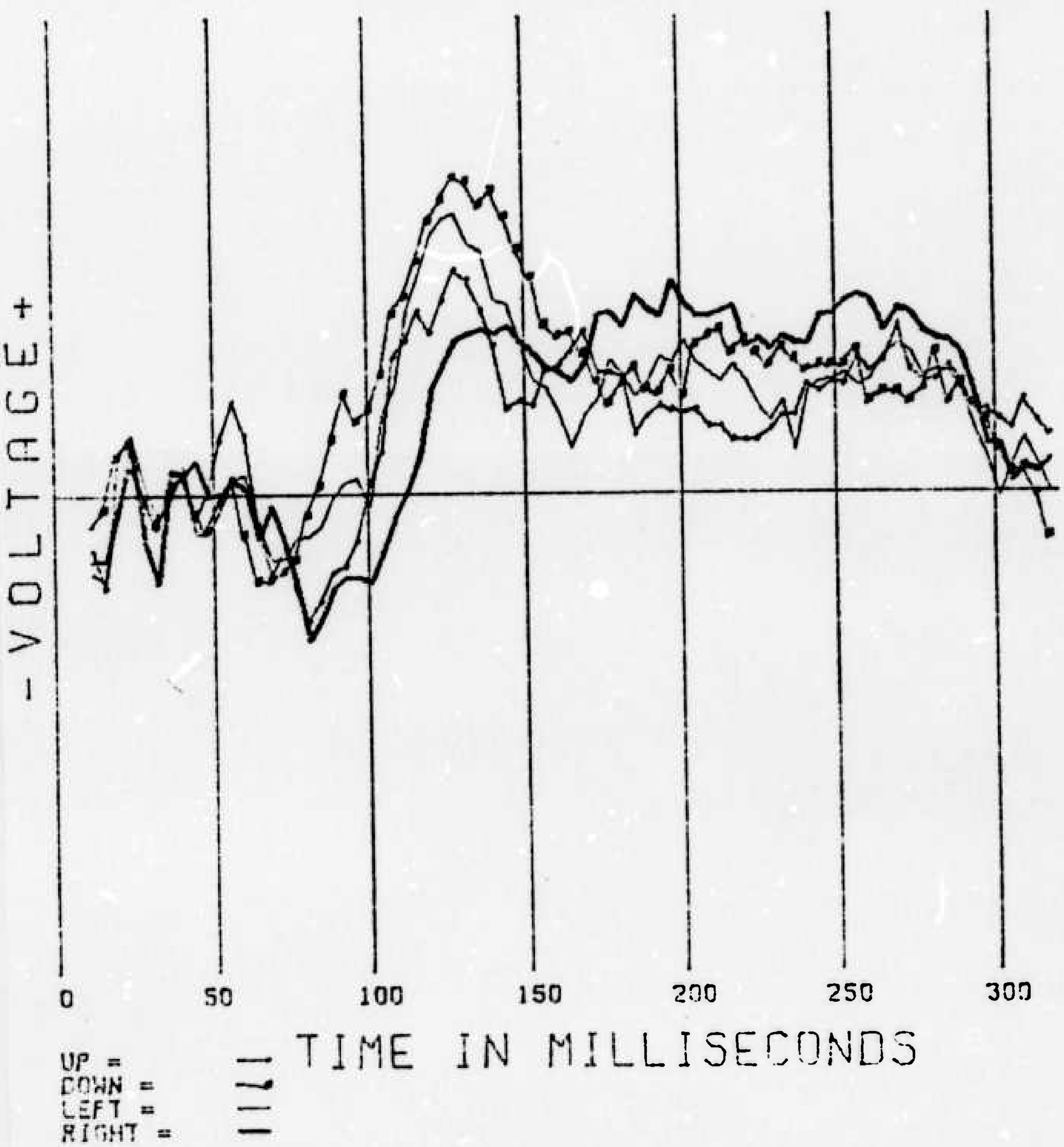
SAG2-MY30-75 ONLINE CONTROL CH5 I-OZ
50 EPOCH AVERAGE X 2.5, EXPR=CB41

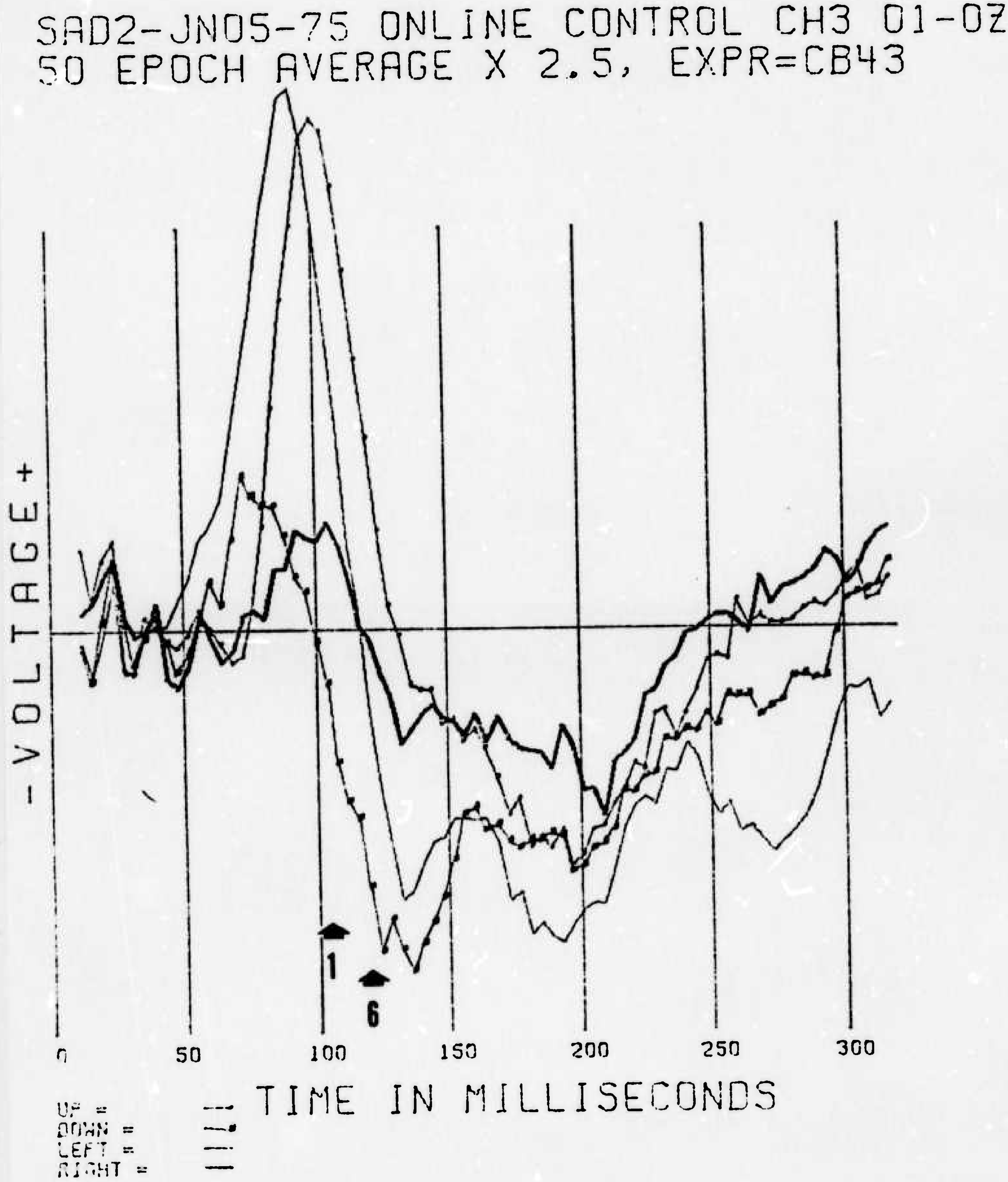


SAD2-JN05-75 ONLINE CONTROL CH1 OZ-A
50 EPOCH AVERAGE X 2.5, EXPR=CB43

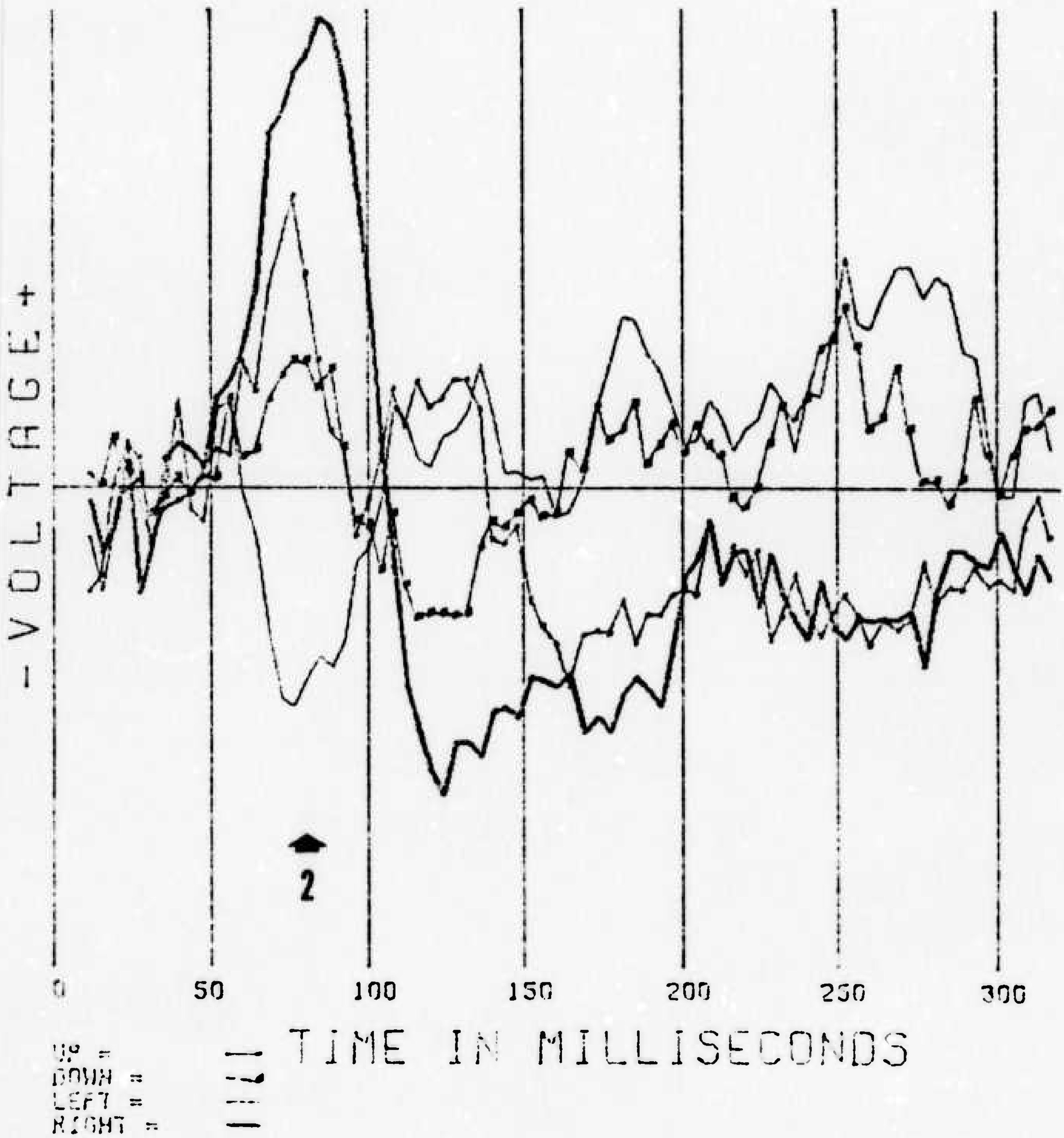


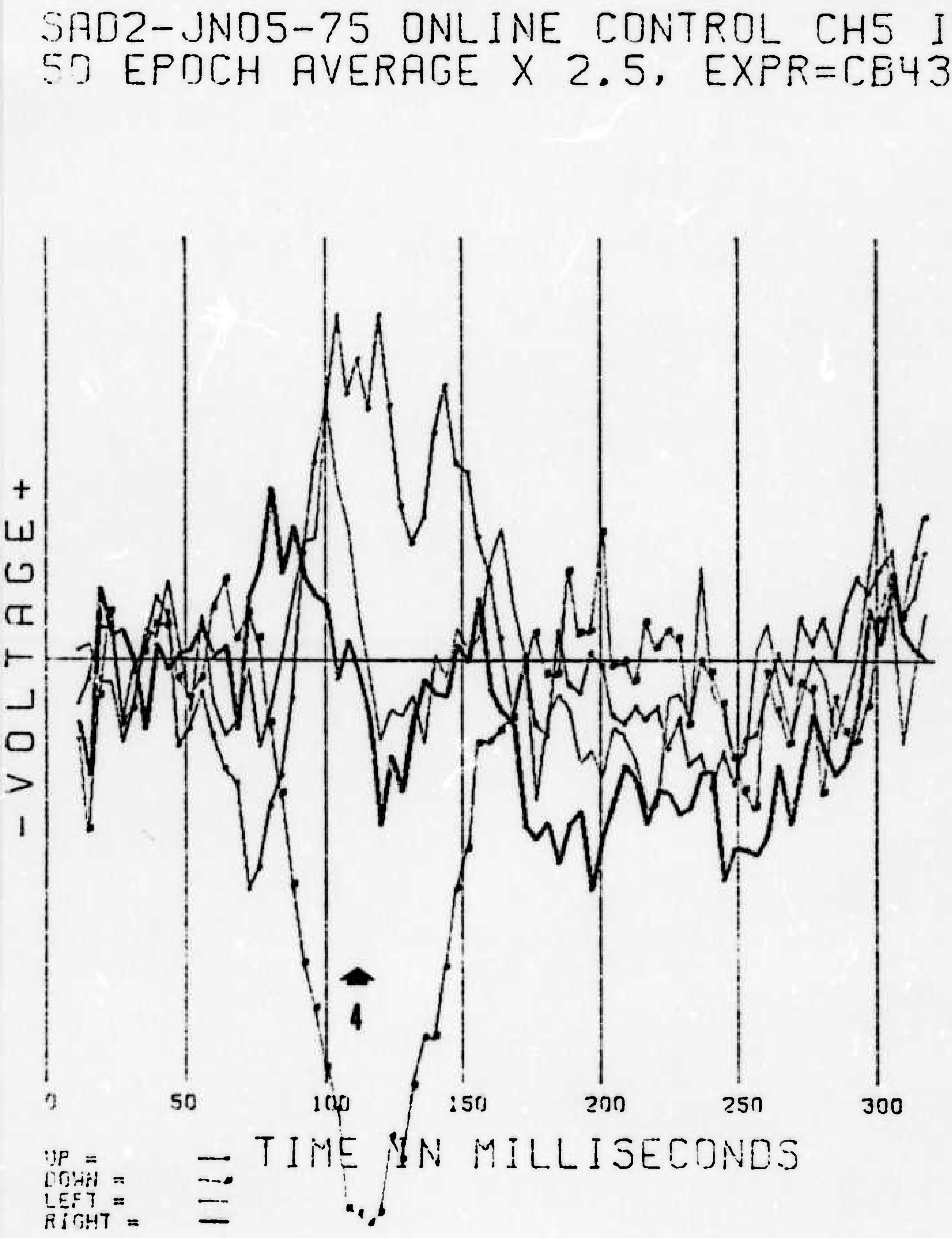
SAD2-JN05-75 ONLINE CONTROL CH2 PZ-OZ
50 EPOCH AVERAGE X 2.5, EXPR=CB43



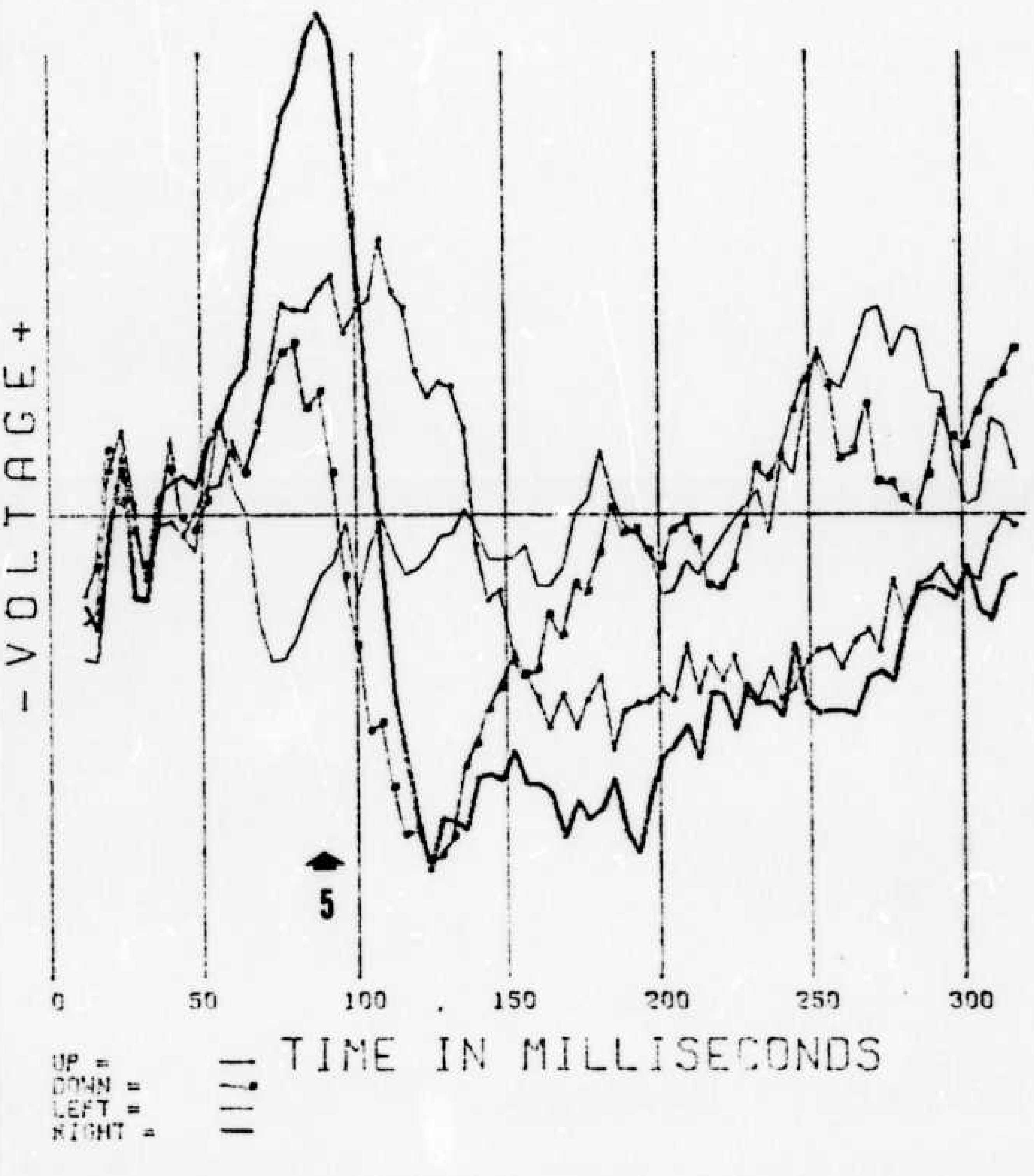

SAD2-JN05-75 ONLINE CONTROL CH3 01-0Z
50 EPOCH AVERAGE X 2.5, EXPR=CB43
-VOLTAGE+
1
6
0
50
100
150
200
250
300
TIME IN MILLISECONDS
UP =
DOWN =
LEFT =
RIGHT =

SAD2-JN05-75 ONLINE CONTROL CH4 O2-OZ
50 EPOCH AVERAGE X 2.5, EXPR=CB43

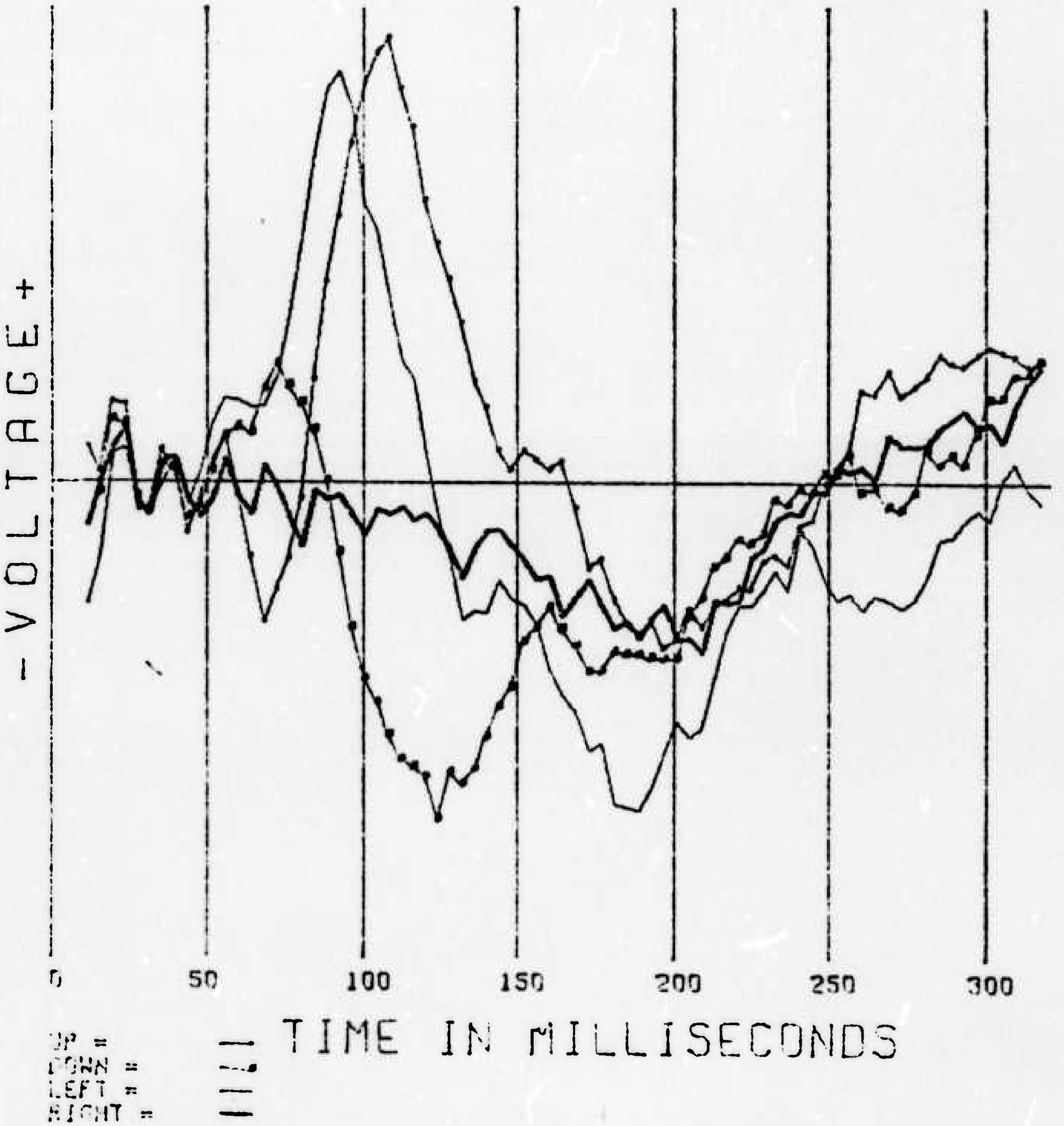



SAD2-JN05-75 ONLINE CONTROL CH5 I-OZ
50 EPOCH AVERAGE X 2.5, EXPR=CB43
-VOLTAGE+
0
50
100
150
200
250
300
TIME IN MILLISECONDS
UP =
DOWN =
LEFT =
RIGHT =
4

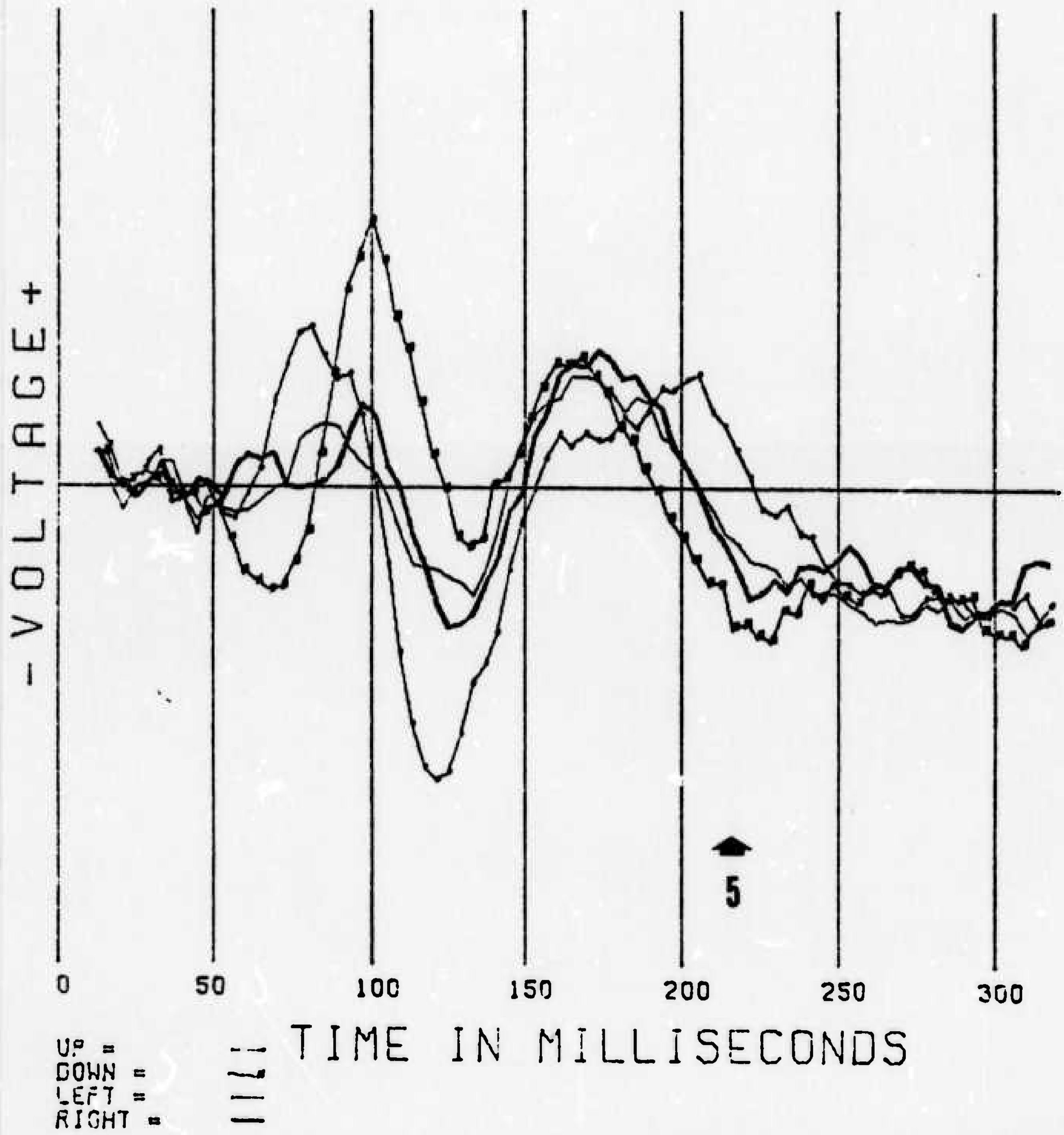
SAD2-JN05-75 ONLINE CONTROL CH5
50 EPOCH AVERAGE X 2.5, EXPR=CB43

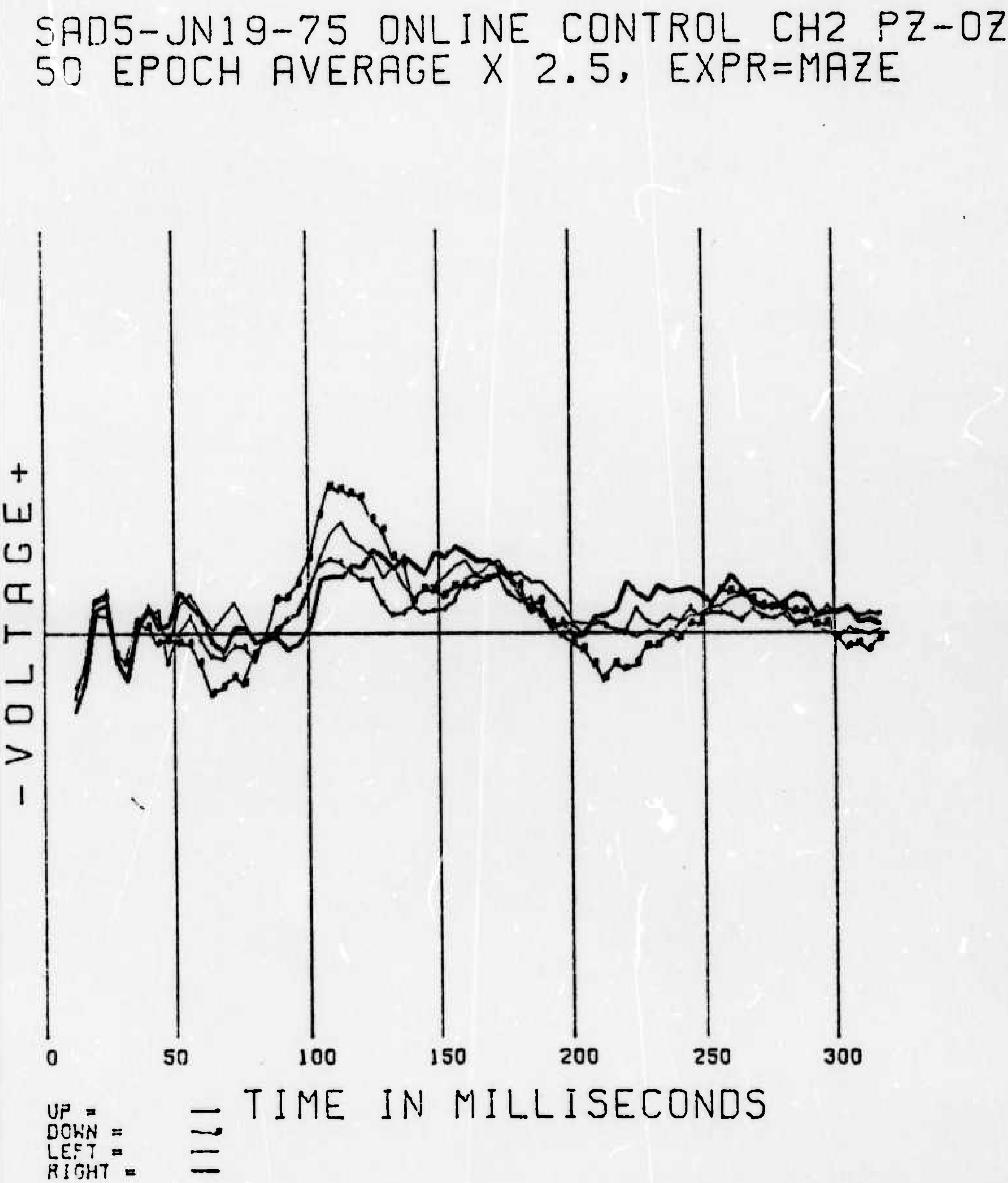


SAD2-JN05-75 ONLINE CONTROL CH7
50 EPOCH AVERAGE X 2.5, EXPR=CB43

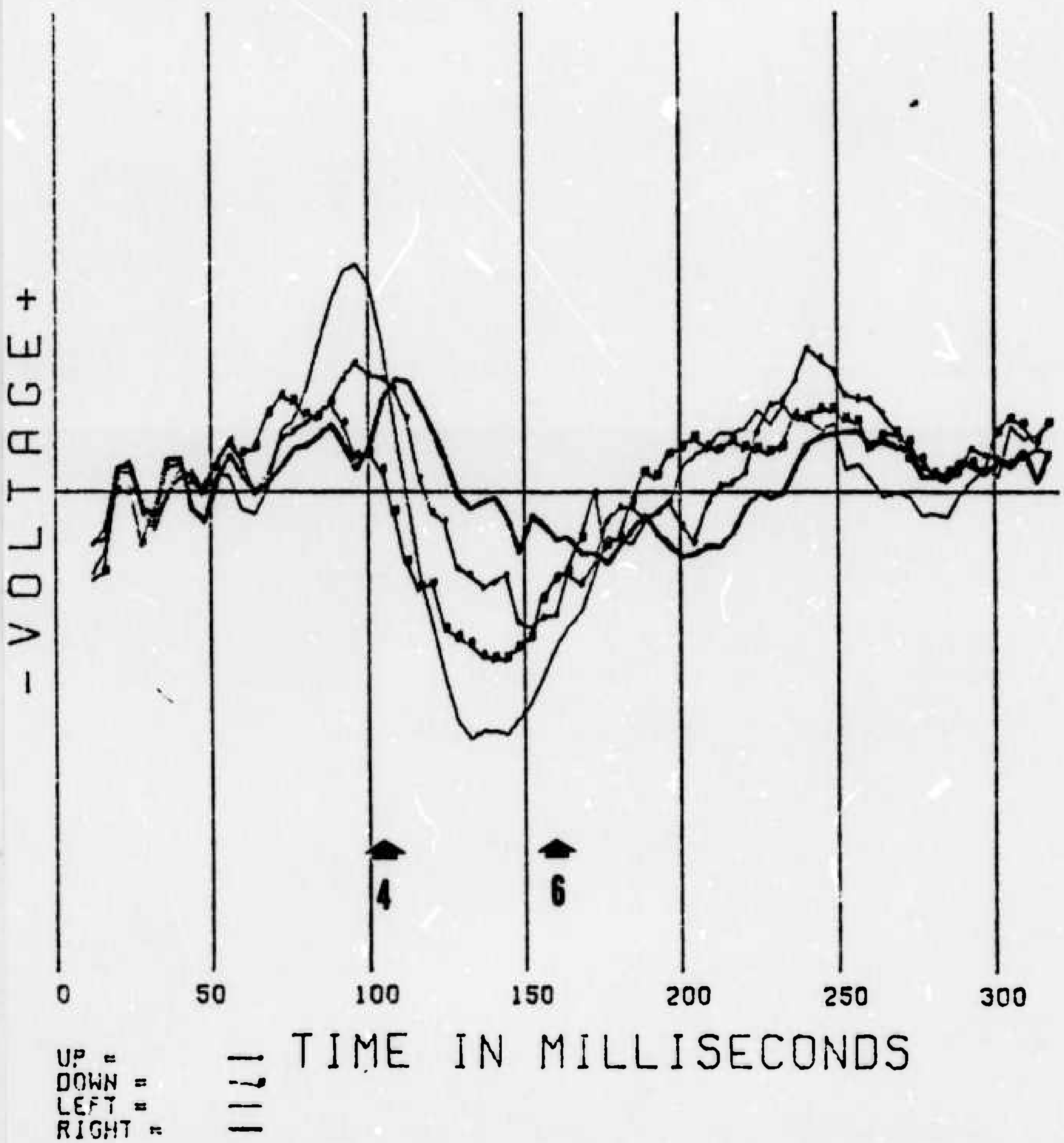


SAD5-JN19-75 ONLINE CONTROL CH1 OZ-A
50 EPOCH AVERAGE X 2.5, EXPR=MAZE

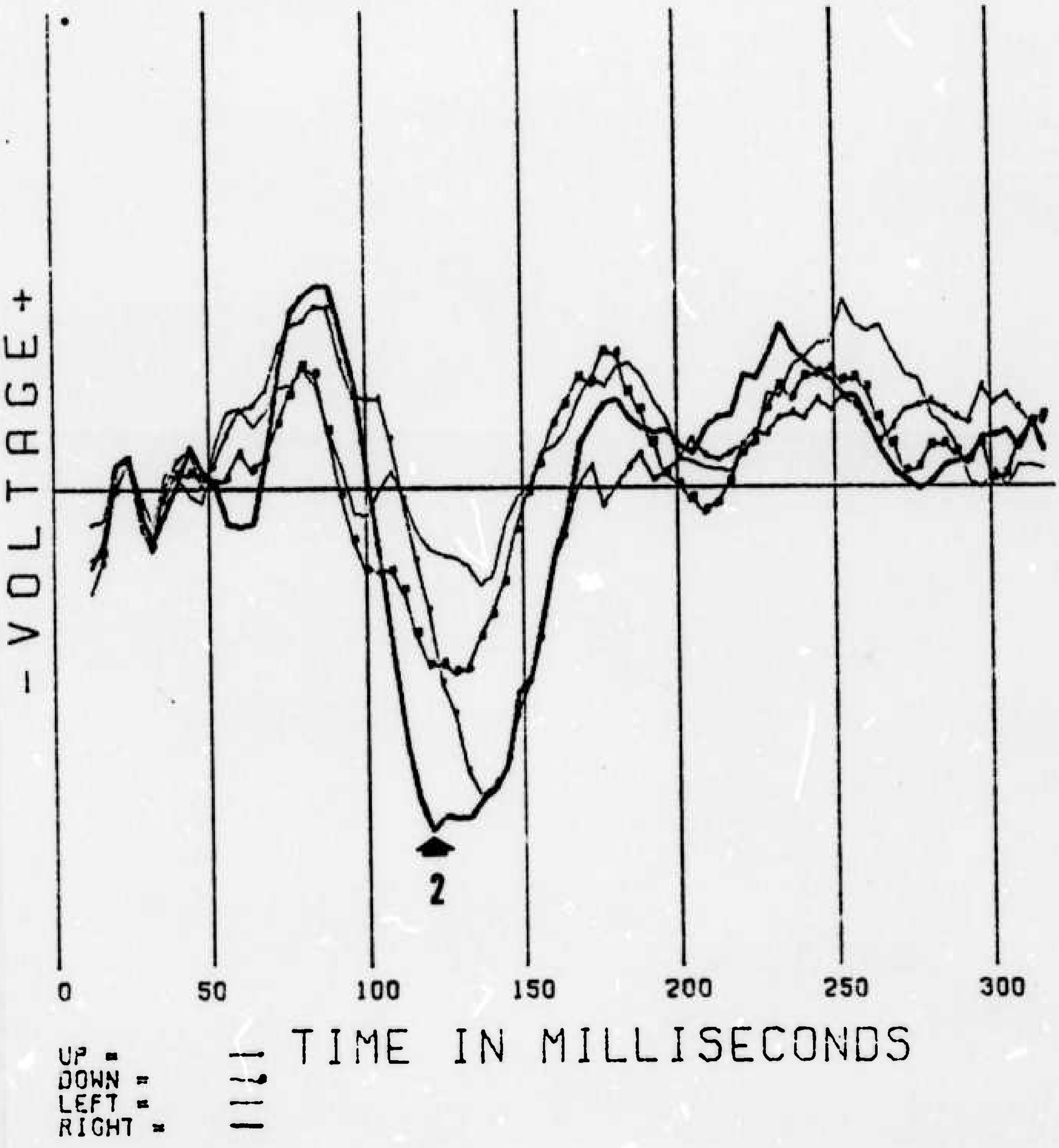



SAD5-JN19-75 ONLINE CONTROL CH2 PZ-OZ
50 EPOCH AVERAGE X 2.5, EXPR=MAZE
-VOLTAGE+
0
50
100
150
200
250
300
TIME IN MILLISECONDS
UP =
DOWN =
LEFT =
RIGHT =

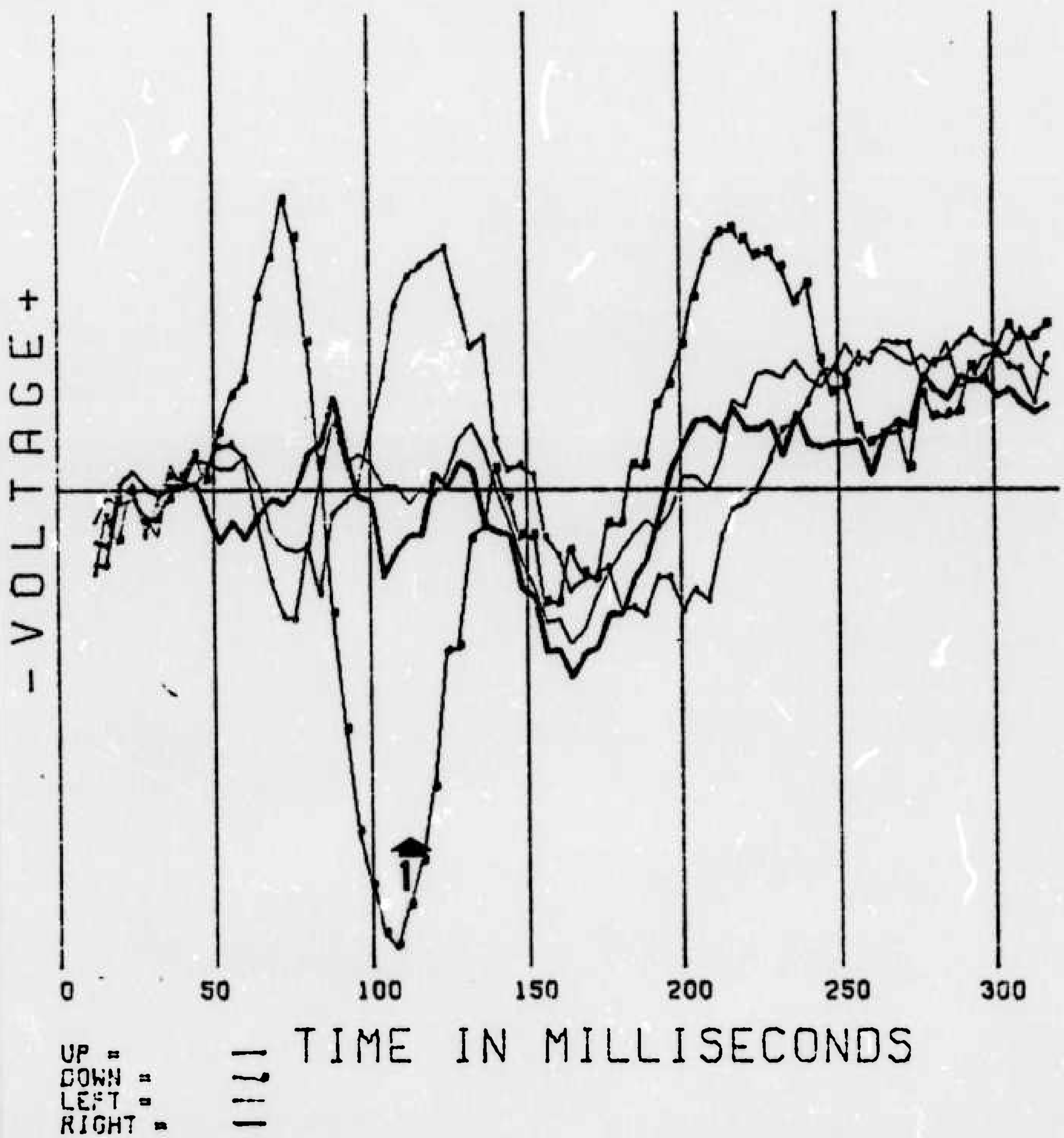
SAD5-JN19-75 ONLINE CONTROL CH3 01-0Z
50 EPOCH AVERAGE X 2.5, EXPR=MAZE



SAD5-JN19-75 ONLINE CONTROL CH4 O2-OZ
50 EPOCH AVERAGE X 2.5, EXPR=MAZE



SAD5-JN19-75 ONLINE CONTROL CH5 I-OZ
50 EPOCH AVERAGE X 2.5, EXPR=MAZE



5. FACILITIES

The project is being conducted under the auspices of the Computer Science Department, University of California, Los Angeles. The principal facility for this project is the computer system at the Brain Computer Interface Laboratory. Laboratory equipment includes three dedicated computers (XDS 930, XDS 920 and IMLAC PDS-1) with complete peripherals (card readers, card punch, rapid access drum, tape drives and line printer.

Experiment subjects are monitored from a specially designed shielded enclosure that contains various input devices and output displays designed in a modular fashion for ease of interfacing with the digital system. The experiment is conducted from an adjacent room containing the control terminals to the system computers, the recording equipment for EEG and other biosignals, as well as voice and video communication devices. The amplified EEG signals are routed to a digitizing station capable of handling 50 simultaneous channels of analog input. During experiments, a dedicated XDS 930 computer with 16K words of core memory and 2M characters on magnetic drum acts as data input controller and real-time experiment controller. All real-time processing functions are performed by the 930 which also creates complete experiment records for off-line batch processing. These contain, for each data "epoch," the experiment parameters (sampling rate, epoch lengths, etc.) specified by the experimenter as well as selected results of on-line computation, subject responses, etc. The 930 also controls an IMLAC PDS-1 minicomputer and display terminal with 8K of memory which is reserved for the generation of visual feedback display and some other functions. In

addition, the PDS-1 as a stand-alone computer can perform extensive calculations and generate sophisticated graphics including animation.

For substantial data processing programs, the main computing power is provided by the campus IBM 360/91 (Campus Computing Network) which is equipped with a large core memory of 4M bytes. The digitized data reaches the IBM 360/91 from the laboratory by a special high speed data line that is used to write and read directly into and from the 360/91 core. The data transfer is controlled with a separate processor (XDS 920) to allow buffering and transfer without interference with experiments. A monitor program in the 360/91 controls both the data flow and the processing protocol from a privileged position with respect to the 360/91 operating system software, thus insuring immediate execution. Complex programs can be performed and the results fed back to the laboratory with minimum turnaround time. The "awakening" of this software system and all subsequent file handling are placed under the campus time-shared system (URSA) and controlled by an IBM 3277 terminal in the laboratory.

Finally, the BCI laboratory computer system has wired-in direct access to the ARPA Network. The network is being used for accessing and transmitting data to other facilities (e.g., UCLA-ATS, CCN, MIT-MULTICS, BBN and LBL.) and for communication with other research groups.